The morphology, mineralogy and genesis of some soils on the moor house national nature reserve

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THE MORPHOLOGY, MINERALOGY AND GENESIS OF SOME SOILS ON THE MOOR HOUSE NATIONAL NATURE RESERVE.

By

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ABSTRACT.

The thesis comprises three parts. One reviews pedological research in the area, discusses the soil forming factors and considers the classification of the soils studied. A chapter is devoted to each pedogenic factor and describes its role in soil formation on the Reserve.

Part two comprises a study of several small limestone grasslands. Their microtopography is described using maps which also show soils. Three surfaces are recognised; the surrounding peat surface, a sub-peat "drift" surface and a dissected limestone surface. Each sub-group in the soil complex is described, i.e. rendzina, brown calcareous soil, acid brown earth and peat podzol: profiles, with analyses, are included. Drift or head is shown to dominate the soil parent material. A contribution from the limestone is present in the shallow soils and dominates in some rendzinas. The inter-relationships of the soils are discussed: they form a sequence reflecting increasing depth of "drift". In the shallow soils plants obtain nutrients

from the limestone thus offsetting leaching. In the deeper soils the limestone merely maintains free drainage. A history of the grasslands is reconstructed. The smaller areas were, almost certainly peat covered but parts of the larger ones may have remained peat free.

Part three discusses eight of the main soil sub-groups on the Reserve. Their distribution, morphology and pedogenesis are considered: profiles are given with analyses. Iron humus podzols are described and the origin of their platey structure and parent material: these soils are shown to be sedentary. Theories on the formation of peaty gleyed podzols are examined in the light of the work at Moor House. Clay movement in some brown earths is discussed. The distribution pattern of the sub-groups is outlined: a drainage sequence containing calcareous members is present. Parent materials of soils on the Pennine escarpment are briefly examined.

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VOLUME II

TABLES TO PARTS

I AND II

MOOR HOUSE

CLIMATOLOGICAL AVERAGES, 1953—65

0255

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Average mean temp. °C	—.7	—.9	1.3	3.9	6.9	9.6	11.0	10.7	9.3	6.6	3.1	.9	5.1
Average max. temp. °C	1.9	1.8	4.4	7.6	11.2	13.8	14.8	14.3	12.8	9.5	5.6	3.6	8.4
Average min. temp. °C	—3.0	—3.6	—1.7	.2	2.7	5.4	7.2	7.1	5.8	3.7	.5	—1.8	1.9
Soil temp. at 1′ depth °C	1.5	1.3	1.9	4.1	7.2	9.9	11.6	11.7	10.3	7.8	4.8	2.7	6.2
Snow days	18	15	11	3	1	0	0	0	0	0	4	11	63
Ground frost days	26	23	24	18	12	5	3	4	6	8	17	22	169
Sunshine hours, daily average	1.2	1.7	2.7	4.1	5.4	5.8	4.4	4.1	3.5	2.8	1.4	1.0	3.2
Rainfall inches	7.4	5.1	4.3	4.9	4.7	4.3	6.2	7.3	6.6	6.9	7.4	8.7	73.6
No. Rain days	21	21	20	20	18	19	21	22	20	21	22	24	248
Wind speed knots*	16.1	14.5	14.0	12.3	12.7	11.8	11.4	11.8	12.1	13.7	13.2	15.2	13.2

*based on incomplete records

TABLE 1

TABLE 2.

GREAT DUN FELL CLIMATOLOGICAL AVERAGES.

	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JLY.	AUG.	SEP.	OCT.	NOV.	DEC.
Average max. temp °C.	-1.0	-0.7	1.1	3.4	7.6	11.2	11.3	11.0	9.4	7.3	2.3	0.1
Average min. temp° C.	-3.8	-3.4	-2.0	-0.8	2.1	5.4	6.0	6.3	4.9	2.9	-1.2	-2.9
Average mean temp. °C.	-2.4	-0.4	-0.4	1.3	4.7	8.3	8.7	8.1	7.1	4.9	0.4	-1.3
Sunshine hours, monthly average.	25.2	32.3	63.5	74.0	107.3	109.4	88.9	64.4	68.3	55.0	34.2	33.9
Sunshine hours, daily average.	0.81	1.15	2.00	2.50	3.44	3.67	2.87	2.34	2.28	1.82	1.13	1.09
Air frost days.	27	24	24	18	6	1	0	0	0	4	20	27
Snow lying.	15	14	7	11	2	0	0	0	0	0	7	13

TABLE 3. A Classification of the Soils of the Moor House National Nature Reserve.

Major Soil Group	Sub-group
Skeletal Soils	Brown Ranker
Calcareous Soils	Rendzinas
	Brown Calcareous Soils
Brown Earths	Normal Acid Brown Earths
	Normal Acid Brown Earths with gleying.
	High level Acid Brown Earth
	High Level Acid Brown Earth with gleying.
Podzolic Soils	Brown Podzolic Soils
	Podzolic Soils with Gleying.
Podzols	Humus Iron Podzols
	Peaty Podzols and Peaty Gleyed Podzols.
Gley Soils	Gley Podzolic Soils
	Peaty Gleys
	Flush Gley soils
	Ground Water Gley soils (Warp soils)
Organic Soils	Blanket peat.
	Basin peat.

TABLE 4

Pebble (2 m.m. - 2 c.m.) Counts on the Clay Loam over the Tyne Bottom Limestone.

Sample no.	Quartz fragments	Sandstone	Shale	Decalcified limestone.	Vein material	Limestone	No. counted
R.S. 2.	8	31	3	2	37	19	100
R.S. 27.	-	42	16	8	36	-	100
R.S. 28.	4	40	12	-	44	-	100
M.H. 8	15	61	16	-	8	-	200
M.H. 9	9	65	20	-	6	-	200

(The above figures are expressed as percentages).

Rough Sike Site R.S. 2 - Rendzina (Profile, p. 146).
R.S. 27 Brown Calcareous Soil.
R.S. 28

Green Hole Site M.H. 8 Peaty Gleyed Podzol (Profile, p. 173).
M.H. 9

TABLE 5.

Comparison of the Clay Minerals and Heavy Minerals in the Clay Loam over the Tyne Bottom Limestone with those of the Insoluble Residue of that limestone.

Clay Minerals				Heavy Minerals					Profile no. Soil Type.
Sample	Chlorite	Kaolin	Illite	Rutile	Zircon	Fluorite	Tourmaline	Garnet	
Insoluble Residue	V.S	M	V.W.		X	X			
R.S. 1.	S.	W	M	X	X	X	X	X	I R.
R.S. 2.	V.S.	W	V.W.	X	X	X	X		I R.
M.H. 1.	S.	W.	S.	X	X	X	X	X	3 B.C.S.
M.H. 2.	S.	W.	M.	X	X	X	X	X	3 B.C.S.
M.H. 7.	M.	W.	V.S.	X	X	X	X	X	7 P.G.P.
M.H. 9.	M.	M.	S.	X	X	X	X	X	7 P.G.P.

TABLE 6.

Mechanical Analyses of the Clay Loam over the Tyne Bottom Limestone and the Insoluble Residue of that Limestone.

Sample.	I. Sand	I. Silt	Clay	Profile no., Soil Tyne and Horizon
Insoluble Residue	66.0	22.0	12.0	
R.S.1.	35.6	32.2	32.2	I R. - A
M.H.1.	36.5	31.7	31.8	3 B.C.S. - A
R.S.27	36.6	23.1	40.3	11 B.C.S. - B
MH 8	46.8	13.6	39.6	7 P.G.P. - B
MH 9	39.4	22.7	37.9	7 P.G.P. - C
MH 10	43	20.6	36.4	7 P.G. - A_{2G}

TABLE 7

Analytical Data for the Stony Clay Loam found over the Tyne Bottom Limestone.

Sample.	Soil type	Mechanical Analyses			Pebble Counts (2 cm-2 m.m.) %			
		I. Sand	I Silt	Clay	Sandstone	Shale	Vein Material.	Decalcified Limestone.
R.S. 16	A.B.E.	46.1	22.8	31.1	5	3	73	19
R.S. 22	A.B.E.	49.0	26.6	24.4	14	5	69	12
R.S. 23	A.B.E.	48.3	20.3	30.4	24	0	62	10
Insoluble Residue		66.0	22.0	12.0	-	-	-	-

(In the 'pebble counts' 3 x 100 fragments were identified and counted).

TABLE 8

Analytical Data for the Clay Layer found over the Tyne Bottom Limestone.

Mechanical Analyses

	U.S.Sand	I.Sand	I.Silt	Clay	U.S. Silt
Clay	-	7.4	38.6	54.2	47.8
Insoluble residue	65.8	66.0	22.0	12.0	42.2

Clay Minerals

	Chlorite	Illite	Kaolin
Clay	V.S.	W.	W.
Insoluble residue	V.S.	V.W.	M.

Heavy Minerals

	Zircon	Fluorite	Garnet	Tourmaline	Rutile	Sphere
Clay	x	x		x		
Insoluble residue	x	x				

TABLE 9

Various Analytical Results for the Sandy Loam found over the Tyne Bottom Limestone.

Sample no	Mechanical Analysis					Profile no
	U.S.Sand	I.Sand	I.Silt.	Clay	U.S.Silt	
RS 14	52.9	73.1	11.2	15.7	31.4	10 A.B.E.
RS 26	51.0	68.1	17.0	14.9	34.1	11 B.C.S.
	Clay Minerals					
	Chlorite	Kaolin	Illite			
RS 14	M	V.W.	W			10 A.B.E.
RS 26	M	W.	M			11 B.C.S.
	Pebble Counts					
	Sandstone	Shale	Vein Material	Decalcified Limestone		
RS 14	15	9	73	3		10 A.B.E.
RS 26	16	5	77	2		11 B.C.S.
	(No counted = 3 x 100)					

<u>TABLE 10.</u>

<u>Chemical Analyses of Parent Materials found over the Tyne Bottom Limestone.</u>

Total Contents (%)

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O	Soil sub-group
RS.1	54.8	13.9	7.8	6.2	0.8	0.6	0.85	0.8	0.4	9.3	R
RS.2	55.9	14.1	7.7	6.0	1.1	0.6	0.90	0.9	0.4	8.5	-
MH.1	n.d.	8.0	9.7	0.44	0.84	0.34	1.9	n.d	1.3	n.d	BCS
MH.2	n.d.	8.2	10.9	0.44	1.60	0.28	1.67	n.d.	0.74	n.d	"
RS.26	57.2	12.3	13.2	1.46	0.53	0.63	0.88	0.38	0.97	8.58	BCS
RS.27	54.0	19.4	9.9	0.88	0.57	0.63	1.27	0.53	0.64	9.43	"
RS.28	55.2	18.6	8.9	1.35	0.66	0.60	0.89	0.43	0.62	10.11	"
RS.14	61.5	9.8	10.3	0.5	0.55	0.65	0.89	0.41	0.71	9.85	ABE
RS.15	59.7	12.6	11.9	0.44	0.54	0.66	0.96	0.43	0.85	8.69	"
RS.16	69.0	8.5	10.1	0.39	0.57	0.68	1.52	0.28	1.14	6.86	"
MH.5	n.d	7.1	5.6	0.27	0.73	0.38	1.67	n.d	0.33	n.d	BCS
MH.6	n.d	7.9	5.8	0.29	1.09	0.34	1.76	n.d	0.28	n.d	"
MH.7	n.d	4.2	1.3	0.10	0.05	0.18	1.13	n.d	0.02	n.d	PGP
MH.8	n.d	6.1	8.8	0.15	0.05	0.33	1.65	n.d	0.20	n.d	"
MH.9	n.d	8.0	5.9	0.25	0.05	0.44	2.06	n.d	0.35	n.d	"

Trace Elements (ppm)

	Zr.	Sr.	Rb.	Pb.	Zn.	Cu.	Ni.
RS.1	190	5560	130	1470	1720	60	150
RS.2	165	810	140	1230	1780	60	140
RS.26	140	240	70	1880	2920	45	80
RS.27	185	435	110	1510	2000	50	90
RS.28	175	460	125	1720	1340	60	160
Rs.14	150	260	70	1980	1200	25	50
RS.15	195	315	80	2420	1840	55	70
RS.16	270	230	85	2130	3920	60	100

TABLE 11

Parent Materials of the various Soil Sub-Groups over the Tyne Bottom Limestone.

	R	B.C.S.(1)	B.C.S. (2)	A.B.E.(1)	A.B.E.(2)	P.G.P.	P.G.
Sandy Loam		x		x			
Clay Loam	x	x	x	x	x	x	x
Stony Clay Loam				x			
Clay				x	x	x	x

e.g. B.C.S. (1) is developed with a sandy loam overlying a clay loam.

TABLE 12

Analytical Data for the Stony Loam found over the Scar Limestone.

Sample no.	Mechanical Analysis (%)				
	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt
MH 3	43	64	16	20	37
MH 4	52	70	15	15	33

	Clay Minerals		
	Chlorite	Illite	Kaolin
MH 3	-	W	V.W.
MH 4	-	M	V.W.
Insoluble residue	-	M	W.

	Pebble Count (%)		
	Limestone	Sandstone	Shale
MH 3	46	31	23
MH 4	44	27	29
	(Only 50 fragments were counted in each case)		

TABLE 13

Analytical Data for the Clay Loam found over the Scar Limestone.

Sample no.	Mechanical Analyses (%)				
	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt
MB 9	36.1	45.9	20.6	33.5	30.4
MB 11	34.4	38.5	22.6	38.9	26.7
MB 13	34.2	44.8	19.1	36.1	29.7
MB 15	61.7	51.0	19.2	29.8	31.9

Clay Minerals

	Illite	Chlorite	Kaolin
MB 10	S	-	V.W.
MB 11	S	-	W.
MB 13	M	-	W.
MB 15	S	-	V.W.
Insoluble residue.	M	-	W.

Pebble Counts

	Micaceous Sandstone	Quartzitic Sandstone	Quartz Iron	Concretions	Shale
MB 10	43	26	9	9	13
MB 11	42	29	8	3	18
MB 13	49	22	7	4	17
MB 15	40	31	12	5	12

Heavy Minerals

	Zircon	Fluorite	Tourmaline	Rutile	Garnet
MB 10	x	x	x	x	x
MB 11	x	x	x	x	x
MB 13	x	x	x	x	x
MB 15	x	x	x	x	x
Insoluble residue	x	x	-	-	-

TABLE 14.

Chemical Data for Parent Materials found over Scar Limestone.

Total Contents.

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	Soil sub-group
MH.4	n.d	4.9	5.9	0.19	1.22	0.16	1.17	n.d	0.56	R
MH.5	n.d	5.6	5.9	0.21	1.72	0.15	1.27	n.d	0.53	"
MB.9	n.d	7.3	0.4	0.29	0.31	0.94	1.0	n.d	0.01	PGP
MB.11	n.d	9.2	5.7	0.60	0.90	2.08	1.1	n.d	0.39	"
MB.12	n.d	7.3	0.5	0.16	0.05	0.10	0.8	n.d	0.01	PGP
MB.13	n.d	6.6	11.8	0.15	0.05	0.12	0.9	n.d	0.12	"
MB.15	n.d	9.2	5.6	0.23	0.15	0.17	1.2	n.d	0.11	"
MBF.2	56.5	16.50	10.29	0.59	0.48	0.70	1.49	1.17	0.85	ABE
MBF.3	59.0	19.25	5.75	0.59	0.56	0.77	4.47	0.71	0.11	
MBF.4	59.4	19.55	6.17	0.69	1.02	0.80	2.05	0.64	0.16	

Trace Elements (ppm)

	Zr	Sr	Rb	Pb	Zn	Cu	Ni
MH.4	280	280	210	760	390	70	170
MH.5	240	234	215	750	390	110	170
MB.12	470	540	110	175	0	30	60
MB.13	495	240	75	175	55	25	40
MB.14	645	330	110	300	130	40	65
MB.15	515	380	105	580	410	60	160

TABLE 15

Analytical Data for the Clay, found on the Moss Burn - Flush Site

Sample no.	Mechanical Analyses (%)				
	U.S.Sand	I.Sand	I.Silt.	Clay	U.S.Silt
MBF 1	11.8	19.00	23.8	57.2	31.0
MBF 2	22.6	25.9	25.4	48.7	29.6
MBF 3	-	7.5	30.1	62.4	37.5
MBF 4	11.2	19.2	30.3	50.5	38.3

Clay Minerals

	Chlorite	Illite	Kaolin
MBF 2	-	S	V.W.
MBF 3	-	S	V.W.
MBF 4	-	M	V.W.
Insoluble residue	-	M	W.

Pebble Counts (%)

	Sandstone	Shale	Limestone	Iron concretions	Quartz
MBF 1	42	16	11	14	17
MBF 2	33	21	9	24	11
MBF 3	38	26	17	15	4
MBF 4	39	13	23	11	14

Heavy Minerals

	Fluorite	Zircon	Garnet	Tourmaline	Rutile	Sphene
MBF 1	x	x		x	x	
MBF 2	x	x	x		x	
MBF 3	x	x	x	x	x	
MBF 4	x	x	x	x	x	x
Insoluble residue	x	x				

TABLE 16

Analytical Data for the Clay Layer found over the Scar Limestone.

	Mechanical Analysis				
	U.S.Sand.	I.Sand	I.Silt.	Clay.	U.S.Silt
Clay	10.8	15.1	29.1	45.8	43.4

Clay Minerals

	Chlorite	Illite	Kaolin
Clay	-	W	W
Insoluble residue	-	M	W

Heavy Minerals

	Zircon	Fluorite	Garnet	Tourmaline	Rutile	Sphene
Clay	x	x			x	
Insoluble residue	x	x				

TABLE 17

Analytical Data for the Silty Loam found over the Four Fathom Limestone.

Sample	Mechanical Analyses				
	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt
HH 6	-	18.6	54.9	26.34	73.6
HH 9	15.0	23.3	56.1	20.6	64.4
Insoluble residue	22.1	42.4	47.4	10.2	67.7

Clay Minerals

	Chlorite	Illite	Kaolin
HH 6	-	M	V.W
HH 9	-	M	V.W.
Insoluble residue	-	M	-

Pebble Counts

	Sndstone	Shale	Decalcified Limestone
HH 6	67	15	18
HH 9	45	19	36

Heavy Minerals

	Fluorite	Zircon	Garnet	Tourmaline	Rutile	Apatite
HH 6	x	x	x	x	x	x
HH 9	x	x	x	x	x	
Insoluble residue	x	x				

TABLE 18

Analytical Data for the Silty Clay found over the Four Fathom Limestone.

	Mechanical Analyses				
	U.S.Sand	I.Sand.	I.Silt.	Clay.	U.S.Silt.
HH 10	8.1	18.8	40.6	40.6	51.3
Insoluble residue	22.1	42.4	47.4	10.2	67.7

Clay Minerals

	Chlorite	Illite	Kaolin
HH 10	-	W	W
Insoluble residue	-	M	-

Pebble Counts

	Sandstone	Shale	Decalcified limestone
HH 10	31	23	46
	(Number of fragments counted = 2 x 100)		

Heavy Minerals

	Fluorite	Zircon	Garnet	Tourmaline	Rutile	
HH 10	x	x	x	x	x	
Insoluble residue	x	x				

TABLE 19

Total Iron Contents of Soils Overlying Limestones.

Sample no.	Profile no.	Soil sub-group.	Associated limestone.	Site	Iron Content (%)
M.H. 3	2	R	Scar	Moss Burn - Sheep Fold	5.9
M.H. 4	2	R	Scar	"	5.9
M.B. 1	12	B.C.S.	Scar	"	5.0
M.B. 2	12	B.C.S.	Scar	"	5.7
M.B.F.3	5	A.B.E.	Scar	Moss Burn - Flush Site	5.7
M.B.F.4	5	A.B.E.	Scar	"	6.1
H.H. 6	3	B.C.S.	Four Fathom	Hard Hill - Northern Unit	4.4
H.H. 7	3	B.C.S.	Four Fathom	"	4.1
H.H. 8	6	A.B.E.	Four Fathom	"	4.6
H.H. 9	6	A.B.E.	Four Fathom	"	4.4
M.H. 1	4	B.C.S.	Tyne Bottom	Rough Sike Site	9.7
M.H. 2	4	B.C.S.	Tyne Bottom	"	10.9
R.S.14	10	A.B.E.	Tyne Bottom	"	10.3
R.S.16	10	A.B.E.	Tyne Bottom	"	10.1

TABLE 20A.

NUTRIENT ANALYSES FOR SAMPLES FROM ROUGH SIKE TRENCH.

Profile no. and soil sub-group.	Sample depth (in.).	Sample no.	Ca	Mg	K	Na	N.%
				meq/100g			
IR	0-2	Rs 1	12.8	1.62	0.59	0.27	1.12
	4-6	RS 2	15.2	0.81	0.52	0.16	0.95
10 ABE	1-3	RS 14	0.75	0.60	0.46	0.38	0.46
	4-8	RS 15	0.52	0.13	0.16	0.33	0.23
	10-14	RS 16	0.42	0	0.11	0.35	0.21
	16-20	RS 18	0.60	0	0.11	0.31	n.d.
11 BCS	1-3	RS 26	1.17	0.77	0.09	0.29	0.39
	5-8	RS 27	4.3	0.69	0.13	0.28	0.22
	9-12	RS 28	7.91	0.73	0.17	0.28	0.19

TABLE 20B.

TOTAL CHEMICAL ANALYSES FOR SAMPLES FROM THE ROUGH SIKE TRENCH.

Sample no.	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O
					(%)					
RS.1	54.8	13.9	7.8	6.2	0.8	0.6	0.85	0.8	0.4	9.3
RS.2	55.9	14.1	7.7	6.0	1.1	0.6	0.90	0.9	0.4	8.5
RS.14	61.46	9.77	10.29	0.5	0.55	0.65	0.89	0.41	0.71	9.85
RS.15	59.74	12.63	11.92	0.44	0.54	0.66	0.96	0.43	0.85	8.69
RS.16	68.99	8.49	10.10	0.39	0.57	0.73	1.52	0.28	1.14	6.86
RS.18	84.57	2.64	4.69	0.22	0.65	0.68	1.37	0.28	0.63	4.29
RS.26	57.21	12.28	13.19	1.46	0.53	0.63	0.88	0.38	0.97	8.58
RS.27	53.98	19.49	9.92	0.88	0.57	0.63	1.27	0.53	0.64	9.43
RS.28	55.22	18.62	8.94	1.35	0.66	0.60	0.88	0.43	0.62	10.11

TABLE 21a.

Exchangeable Nutrients of Samples from the Moss Burn Trench.

Profile no. and soil sub-group.	Sample no.	Distance from E.end of trench.	Sample depth (in.)	N%	Na	K	Ca	Mg	P
12 B.C.S.	MB.1	E.end	0 - 3	0.27	0.14	0.29	10.4	0.78	0.03
"	MB.2	E.end	6 - 9	0.25	0.04	0.16	14.75	0.56	0.16
* A.B.E.	MB.3	2'6"	0 - 3	0.24	0.11	0.26	5.55	0.81	0.04
"	MB.4	2'6"	6 - 9	0.25	0.10	0.19	5.15	0.86	0.05
"	MB.5	2'6"	10-13	0.15	0.11	0.14	10.1	0.62	0.06
* P.G.P.	MB.6	5'	6 - 8	0.13	0.06	0.10	3.15	0.56	0.05
"	MB.7	5'	8 -10	0.11	0.08	0.08	2.85	0.56	0.06
"	MB.8	5'	10-14	0.22	0.19	0.16	14.8	0.86	0.20
13 P.G.P.	MB.9	7'6"	6 -10	-	0.04	0.11	6.35	0.28	0.08
"	MB.10	7'6"	10-14	0.12	0.06	0.05	5.45	0.18	0.02
"	MB.11	7'6"	21-25	0.17	0.15	0.07	9.4	0.43	0.05
14 P.G.P.	MB.12	W.end	1 - 3	0.13	0.04	0.06	0.35	0.18	0.07
"	MB.13	W.end	4 - 5	0.10	0.04	0.04	0.32	0.11	0.02
"	MB.14	W.end	7 - 9	0.09	0.04	0.05	0.48	0.13	0.02
"	MB.15	W.end	12-14	0.17	0.16	0.08	10.95	0.33	0.20
					meq. / 100gm.				mgm/100g.

* Profile descriptions not included.

TABLE 21B.

Total Contents of Various Elements in Samples from the Moss Burn Trench.

Sample no.	Percentages							
	Na	K	Ca	Mg	P	Mn	Fe	Al
MB.1	1.11	0.9	0.63	0.31	0.112	0.24	5.0	7.8
MB.2	1.43	1.0	1.00	0.36	0.100	0.33	5.7	7.8
MB.3	1.22	0.9	0.73	0.33	0.130	0.33	6.1	7.8
MB.4	1.38	1.0	0.80	0.36	0.114	0.33	6.2	7.2
MB.5	1.43	1.2	0.73	0.50	0.074	0.27	5.2	8.8
MB.6	0.92	0.9	0.48	0.30	0.060	0.13	3.4	7.1
MB.7	1.55	0.9	0.73	0.36	0.192	0.11	9.4	6.8
MB.8	1.87	1.3	1.15	0.60	0.128	0.39	6.4	9.0
MB.9	0.94	1.0	0.31	0.29	0.035	0.01	0.4	7.3
MB.10	1.47	0.8	0.73	0.36	0.108	0.10	11.7	6.7
MB.11	2.08	1.1	0.90	0.60	0.112	0.39	5.7	9.2
MB.12	0.10	0.8	0.05	0.16	0.016	0.01	0.5	7.3
MB.13	0.12	0.9	0.05	0.15	0.074	0.12	11.8	6.6
MB.14	0.10	1.1	0.05	0.15	0.058	0.11	4.6	7.6
MB.15	0.17	1.2	0.15	0.23	0.058	0.11	5.6	9.2

(Determined by wet chemical methods).

TABLE 22.

SUMMARY OF DETAILES OF THE LIMESTONE GRASSLAND SITES.

Site no.	Name	Associated limestone	Altitude. (ft.O.D.)	Surface stream present	Underground stream present	Shake holes present	Swallow holes present	Sited at a confluence	Soils present R.	B.C.S.	A.B.E.	P.G.P.
1	Moss Burn - Sheep Fold	Scar	2050	X	X	X	X	X	X	X	X	X
2	Moss Burn - Flush Site	Scar	2100			X				X	X	X
3.	The Currick Site	Scar	2100	X	X	X		X	X	X	X	X
4.	Currick Hill Site	Scar	2075	X	X	X		X	X	X	X	X
5.	-	Scar	2075	X	X	X		X	X	X	X	X
6.	-	Scar	2075	X		X		X	X	X	X	X
7.	-	Scar	2100	X		X		X	X	X	X	X
8.	Hard Hill - Eastern Unit	Four Fathom	2200			X				X	X	X
9.	Hard Hill - Northern Unit	Four Fathom	2175			X				X	X	X
10.	Rough Sike Site	Tyne Bottom	1850	X				X	X	X	X	X
11.	Green Hole Site	Tyne Bottom	1800	X		X	X	X	X	X	X	X
12.	Little Dodgen Pot Sike Sites	Tyne Bottom	1850-1875			X	X			X	X	X

FIGURES TO PARTS

I AND II

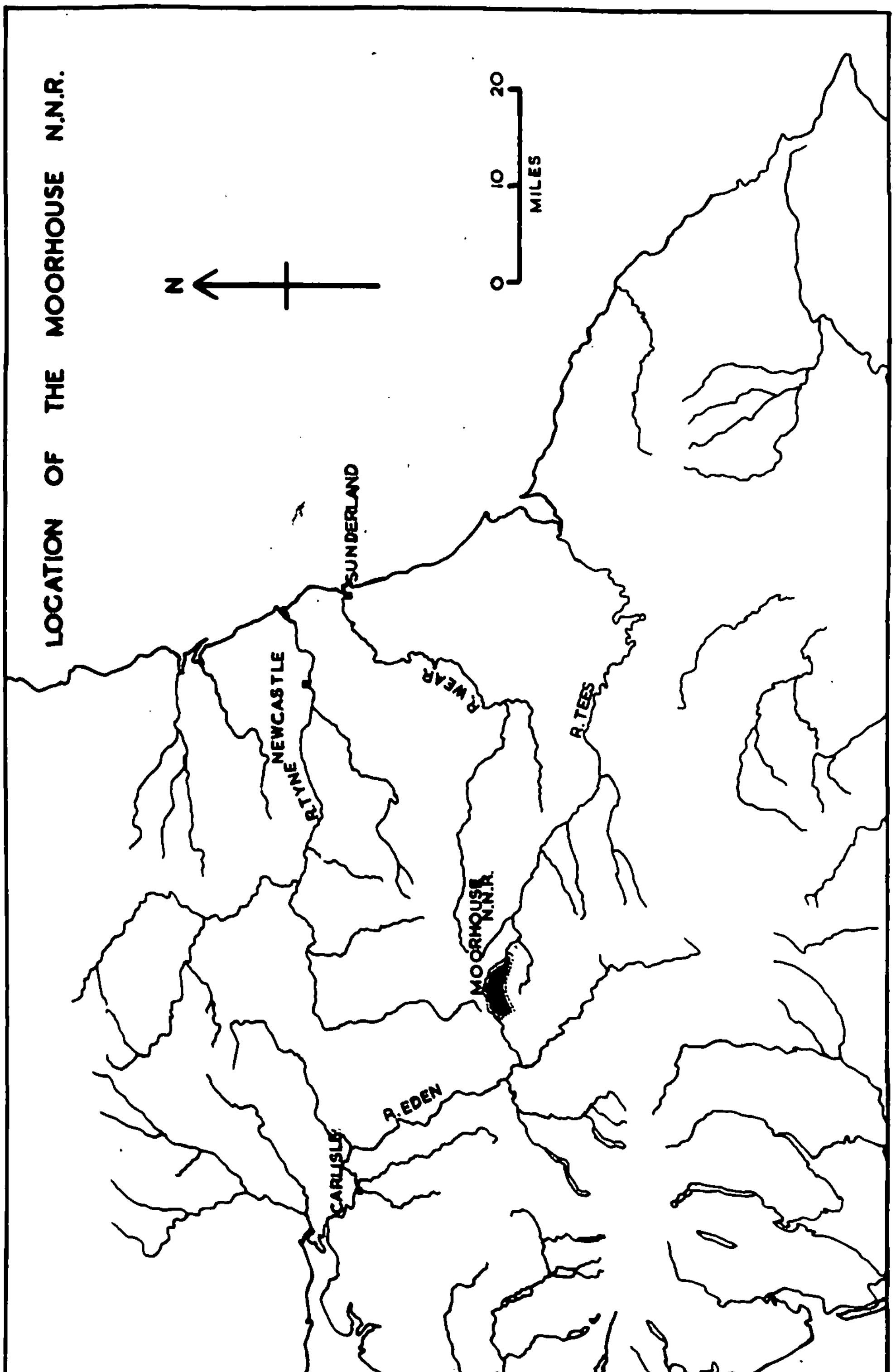

LOCATION OF THE MOORHOUSE N.N.R.
N
0
10
20
MILES
SUNDERLAND
NEWCASTLE
R. TYNE
R. WEAR
R. TEES
MOORHOUSE N.N.R.
R. EDEN
CARLISLE

Fig. 1.

0280

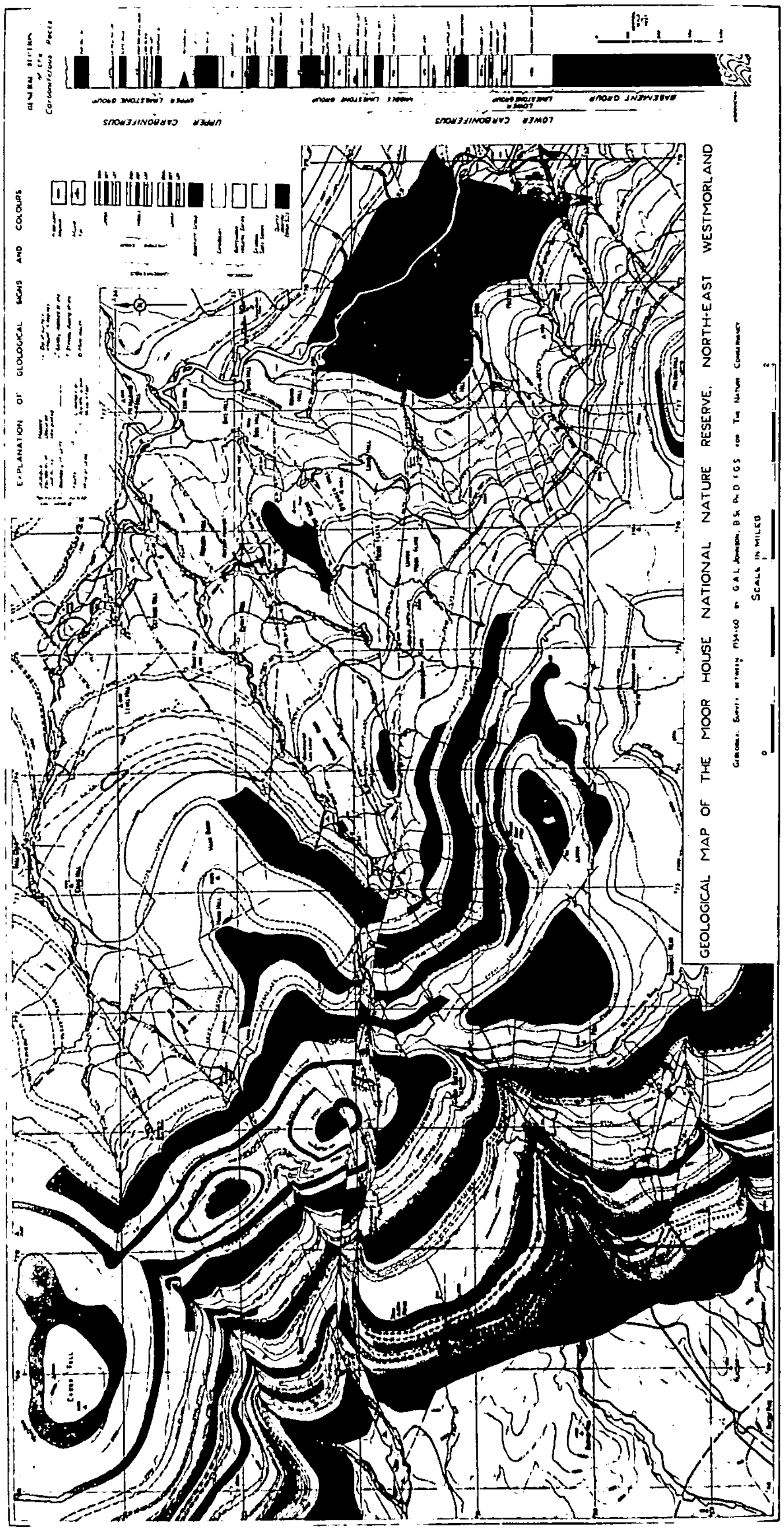
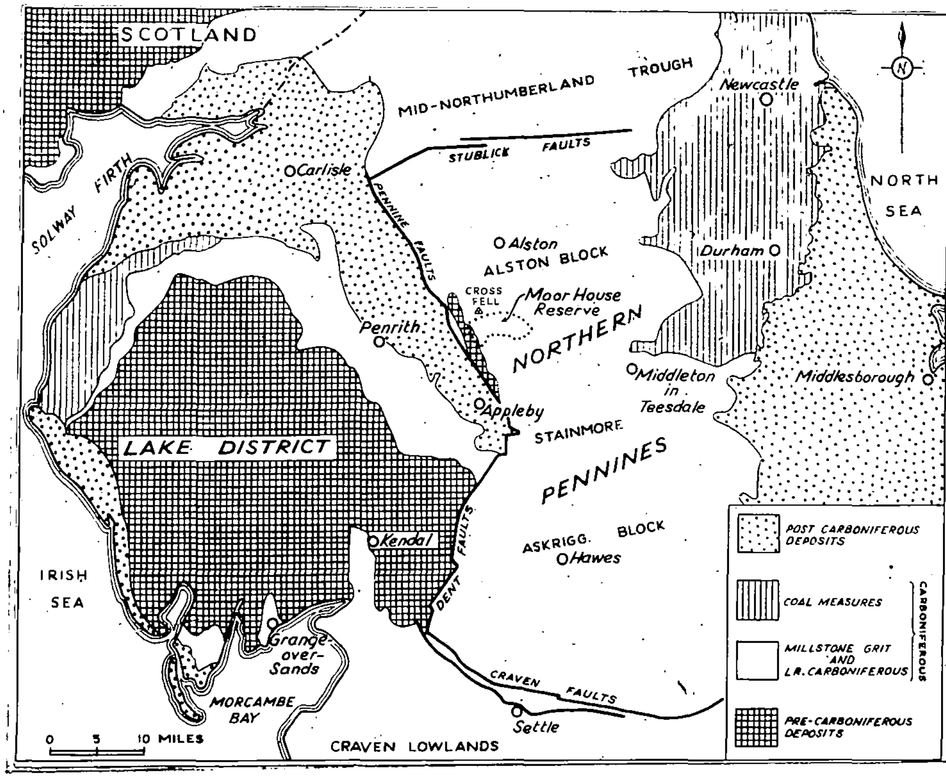

GEOLOGICAL MAP OF THE MOOR HOUSE NATIONAL NATURE RESERVE, NORTH-EAST WESTMORLAND
EXPLANATION OF GEOLOGICAL SIGNS AND COLOURS
UPPER CARBONIFEROUS
LOWER CARBONIFEROUS
SCALE IN MILES

Fig. 2. 0281



GENERAL GEOLOGY OF NORTHERN ENGLAND

Fig. 3.

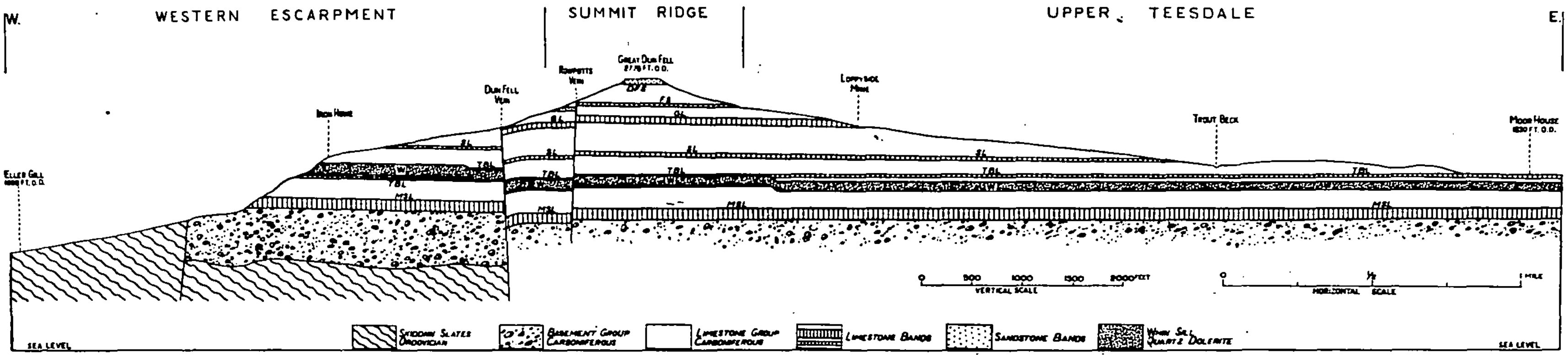
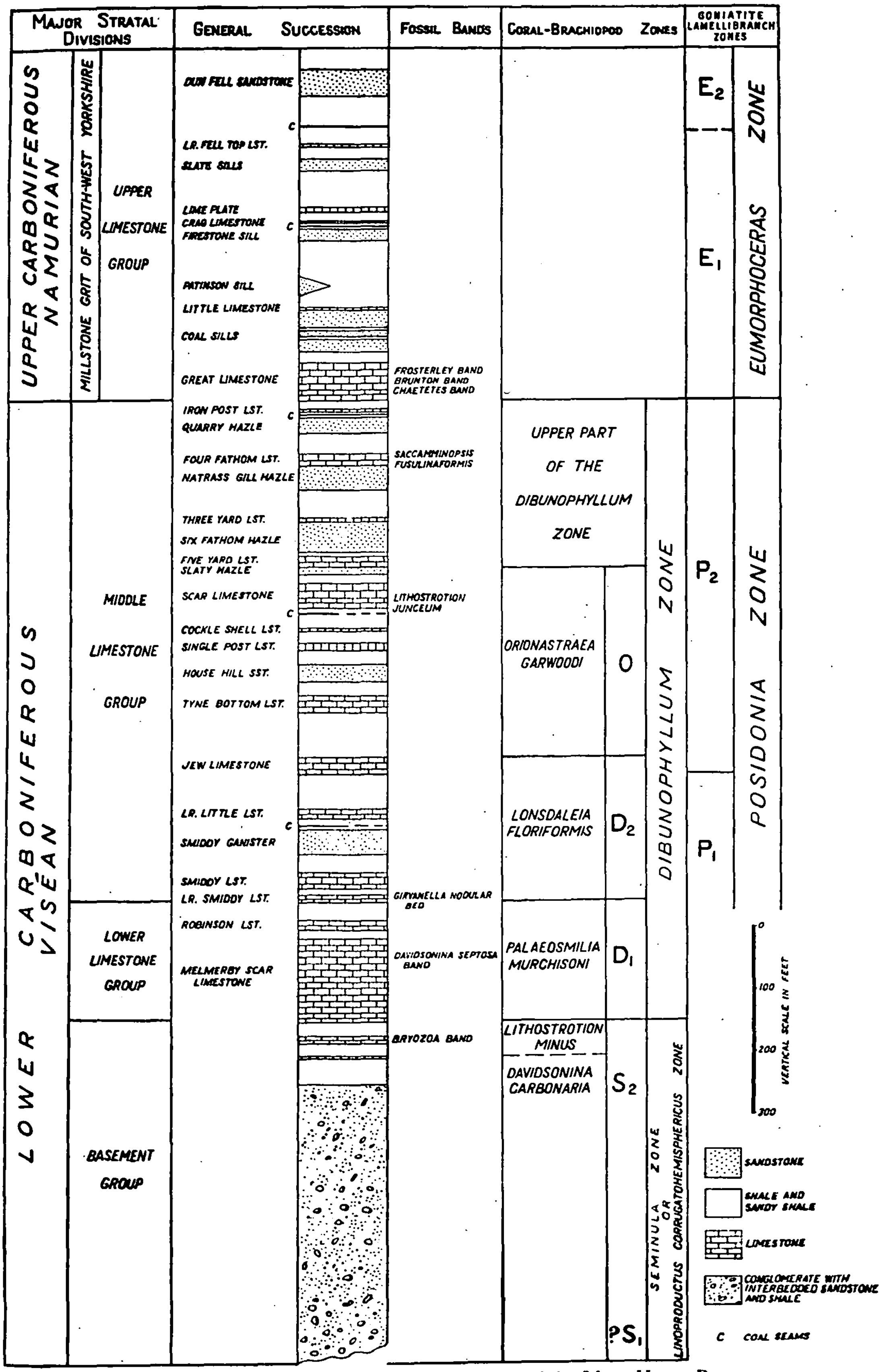


Fig. 4.

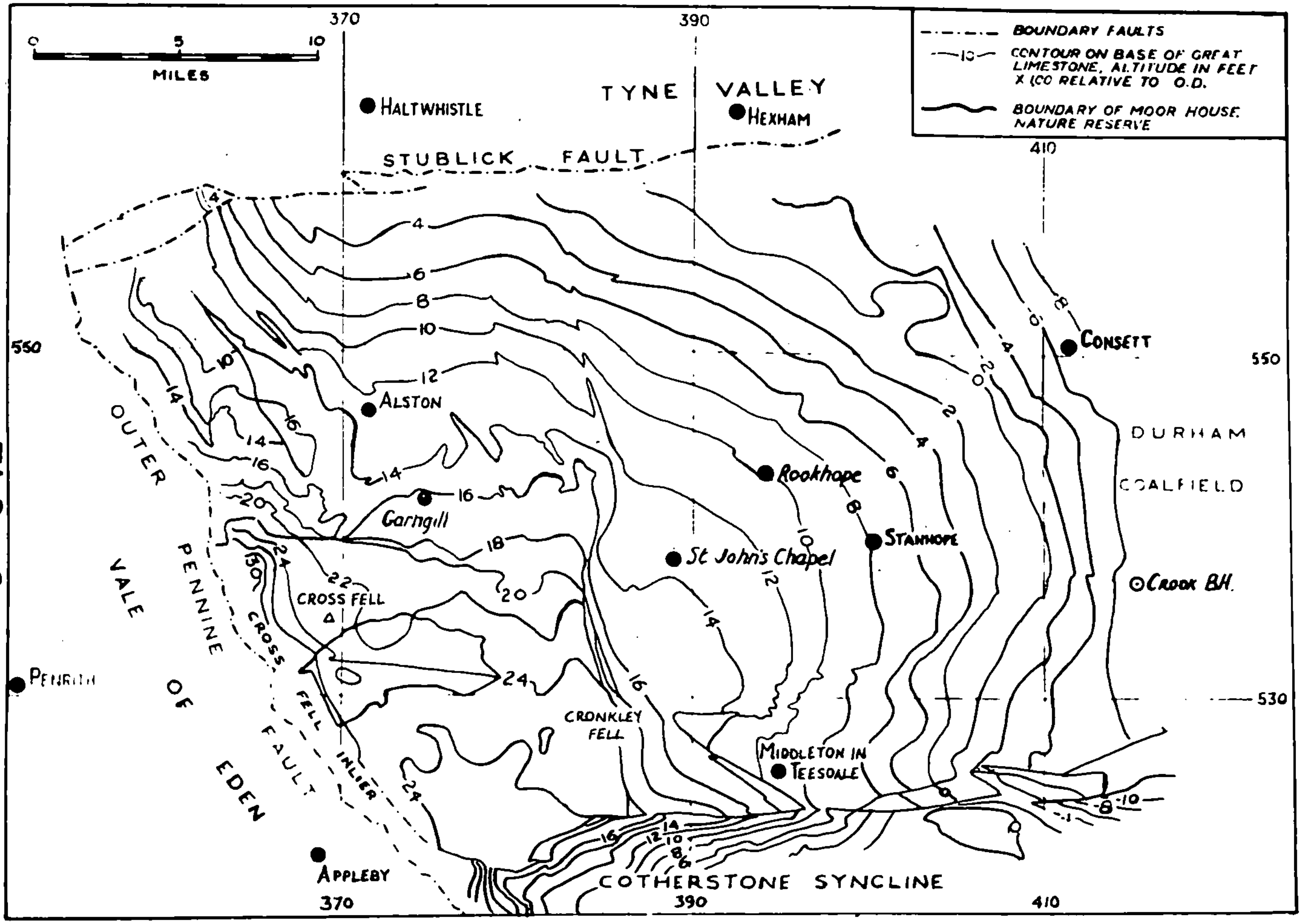
Generalized section across the Moor House Nature Reserve showing the disposition of the geological formations.



General succession of the Carboniferous rocks of the Moor House Reserve.

Fig. 5. 0284

FIG. 6

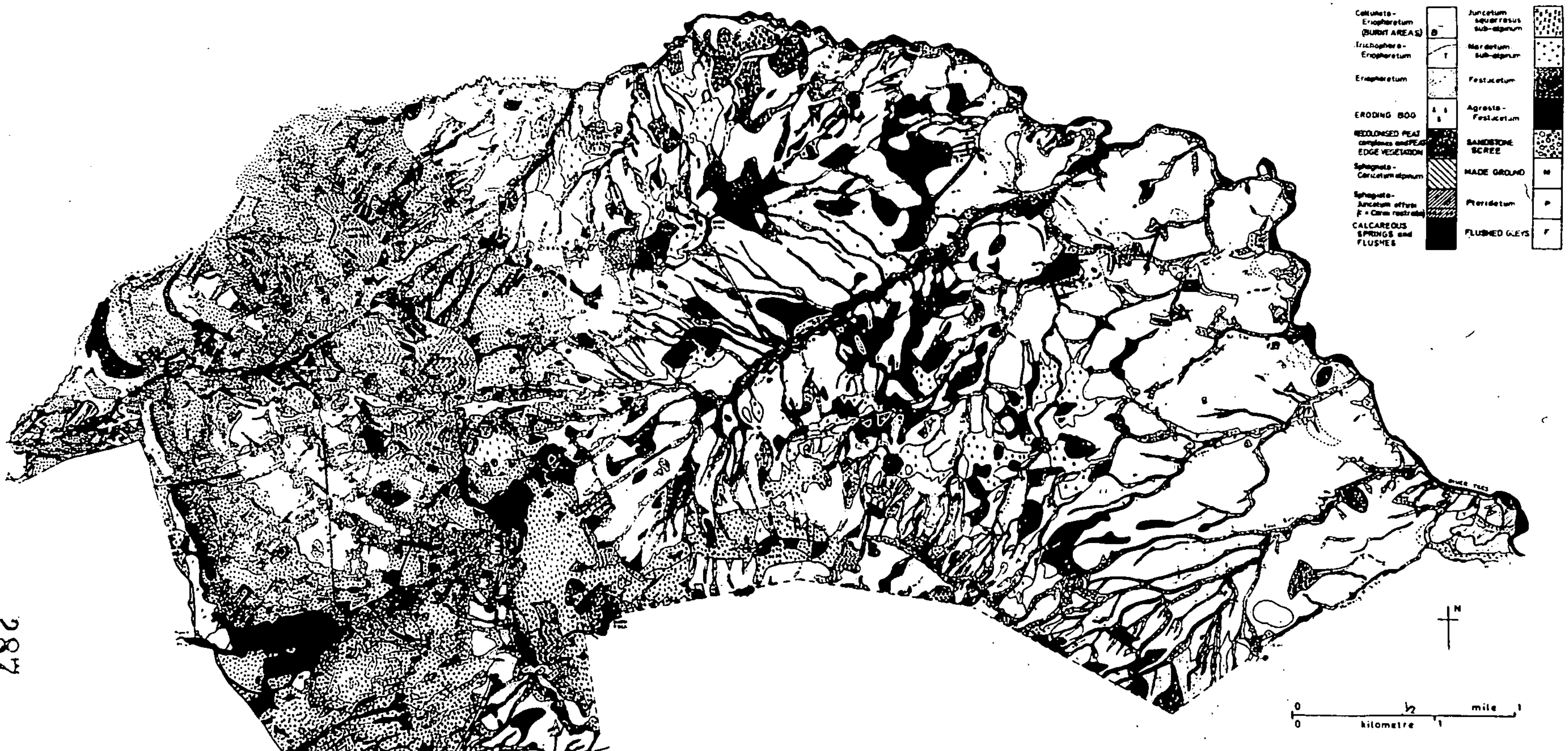


Structure of the Alston Block illustrated by structure-contours on the base of the Great Limestone; heights in hundreds of feet above ordnance datum. Based on Dunham (1959)

DATING			VEGETATION	CLIMATE		ARCHAEOLOGY	
	YEARS	POLLEN ZONE	ENGLAND AND WALES	PERIODS OF BLYTT AND SERNANDER	CLIMATIC VARIATION	FOREST-COVER	CULTURES
POST GLACIAL	2000 – A.D. / B.C. – 500	VIII	ALDER-BIRCH-OAK-ELM-BEECH	SUB-ATLANTIC	RAPID DETERIORATION	CLEARING OF FORESTS BY MAN	NORMAN; ANGLO-SAXON; ROMANO-BRITISH; IRON AGE
	500 – 3000	VIIb	ALDER-OAK-ELM-LIME	SUB-BOREAL			BRONZE AGE; NEOLITHIC
	3000 – 5500	VIIa	ALDER-MIXED OAK FOREST	ATLANTIC	CLIMATIC OPTIMUM (dryness)	FOREST	MESOLITHIC
	5500	VI a b c	PINE-HAZEL	BOREAL			
		V	HAZEL-BIRCH PINE	BOREAL	RAPID AMELIORATION		
	7700 – 8300	IV	BIRCH	PRE-BOREAL			
LATE GLACIAL	8300 – 8800	III	TUNDRA (birch copses)	UPPER DRYAS	COLD (SOLIFLUXION)	GRASS-SEDGE AND OPEN VEGETATION	UPPER PALAEOLITHIC
	8800 – 10000	II	BIRCH WOODS	ALLERØD	MILDER		
	10000	I	TUNDRA (local birch)	LOWER DRYAS	COLD (SOLIFLUXION)		

Late-glacial and Post-glacial chronology after Godwin (1956).

Fig. 8.



VEGETATION MAP of
MOOR HOUSE N.N.R.
area surveyed by A.Eddy, 1960-1962. map copied with
alterations by D.Welch, 1965.

Fig. 9

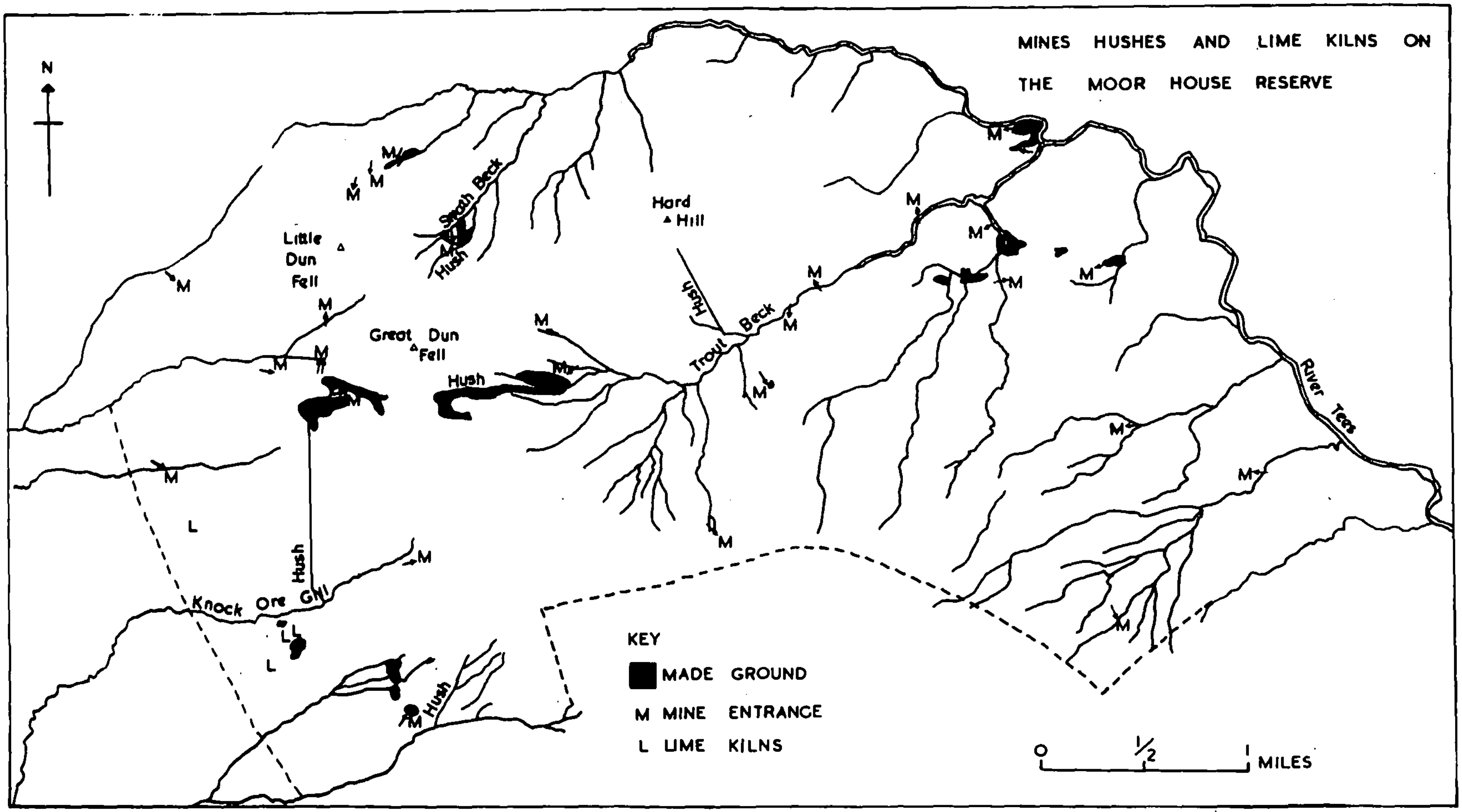

MINES HUSHES AND LIME KILNS ON THE MOOR HOUSE RESERVE
N
Little Dun Fell
Great Dun Fell
Hard Hill
Sleath Beck
Hush
Trout Beck
River Tees
Knock Ore Gill
KEY
MADE GROUND
M MINE ENTRANCE
L LIME KILNS
0 1/2 1 MILES

Fig. 10.

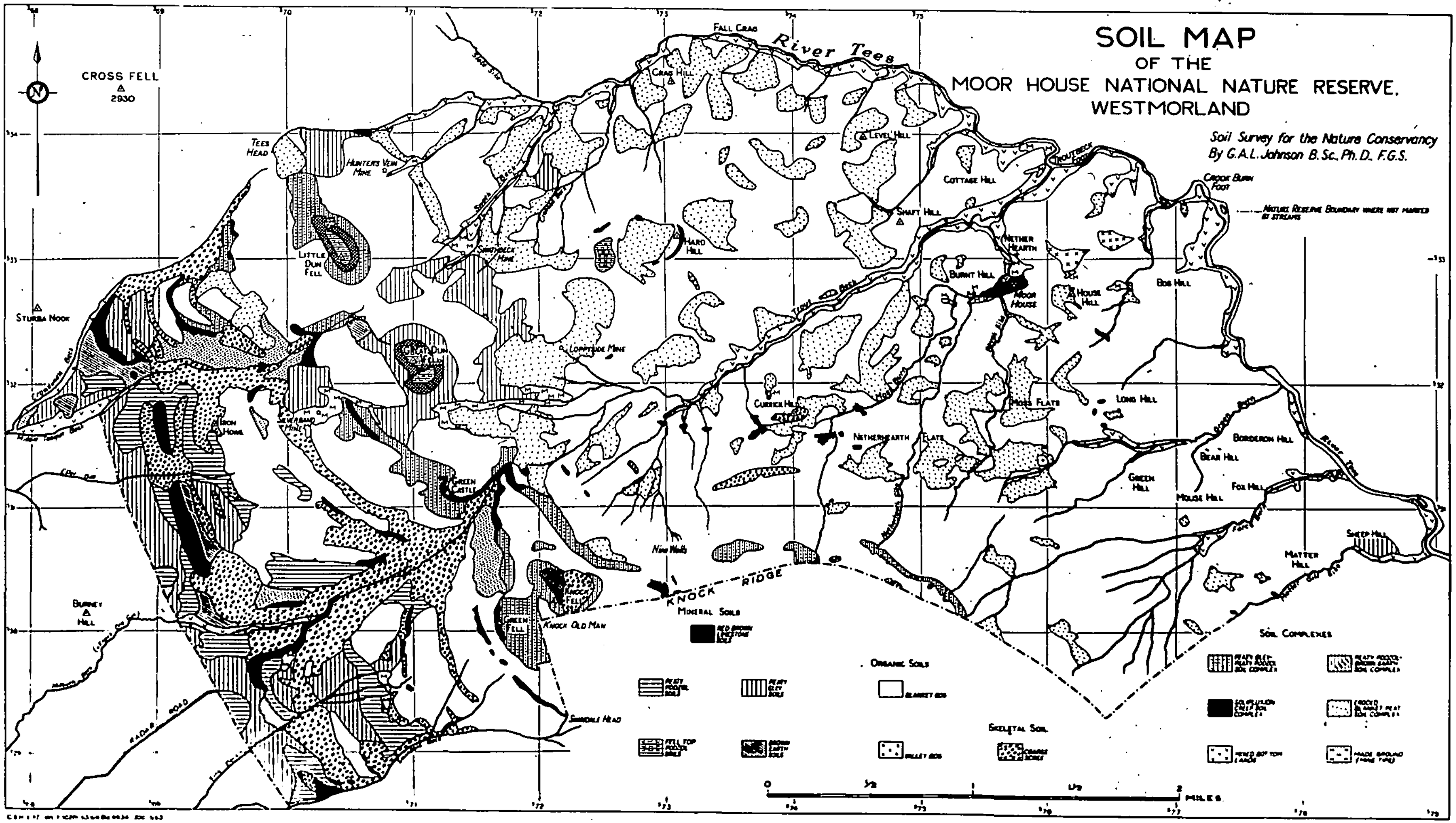

SOIL MAP
OF THE
MOOR HOUSE NATIONAL NATURE RESERVE.
WESTMORLAND
Soil Survey for the Nature Conservancy
By G.A.L. Johnson B.Sc. Ph.D. F.G.S.
CROSS FELL
2930
River Tees
Fall Crag
Crag Hill
Level Hill
Cottage Hill
Shaft Hill
Tees Head
Hunters Vein Mine
Little Dun Fell
Great Dun Fell
Sturba Nook
Nether Hearth
Burnt Hill
Moor House
House Hill
Bog Hill
Long Hill
Moss Flats
Netherhearth Flats
Green Hill
Mouse Hill
Fox Hill
Bear Hill
Borderon Hill
Sheep Hill
Matter Hill
Green Castle
Knock Fell
Green Fell
Knock Old Man
Knock Ridge
Nine Wells
Burney Hill
Crook Burn Foot
Troutbeck Foot
Mineral Soils
Organic Soils
Skeletal Soil
Soil Complexes
MILES

Fig. 11

289

Key to fig. 12

1. Moss Burn - Sheep Fold Site.

2. Moss Burn - Flush Site.

3. The Currick Site.

4. Currick Hill Site.

5.)
6.) Un-named sites discussed with the Currick Hill Site.
7.)

8. Hard Hill - Eastern Unit

9. Hard Hill - Northern Unit

10. Rough Sike Site.

11. Green Hole Site.

12. Little Dodgen Pot Sike Sites.

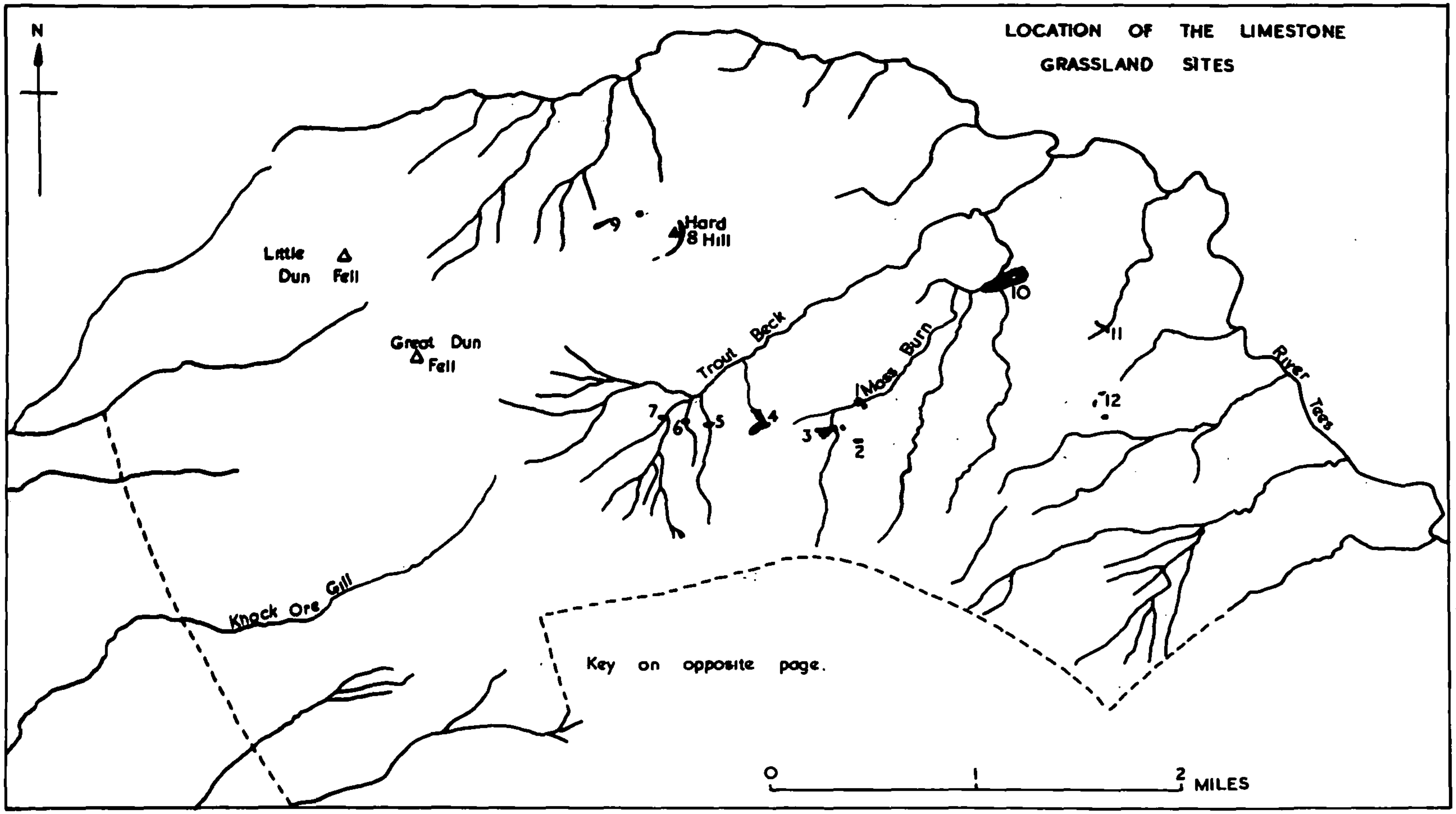

LOCATION OF THE LIMESTONE GRASSLAND SITES
N
Little Dun Fell
Great Dun Fell
Hard Hill
Trout Beck
Moss Burn
River Tees
Knock Ore Gill
1
2
3
4
5
6
7
8
9
10
11
12
Key on opposite page.
0
1
2 MILES

Fig. 12.

Key to Figs. 11 - 26

Rendzina	Limestone blocks through soil indicated
Brown calcareous soil	M Made ground
Acid brown earth	Soil complexes are indicated by mixing symbols e.g.
Peaty gleyed podzol	Concave change of slope
Peaty gley	Convex change of slope
F F F Flushed peaty gley	Vertical face
Blanket peat	Shake hole or Swallow hole
Soils with a large Alluvial contribution	(R) Rain gauge
Limestone pavement	Fence line

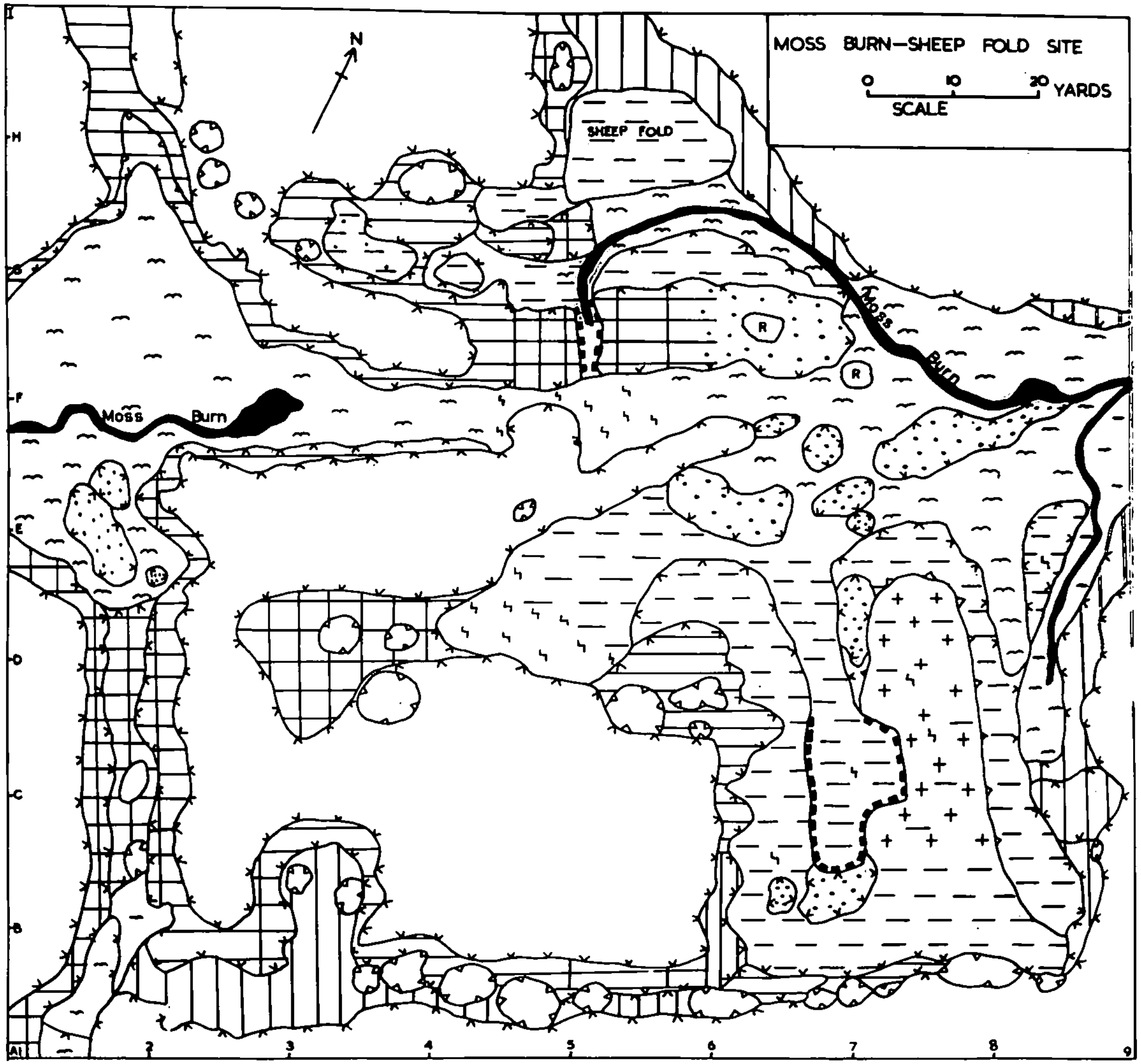
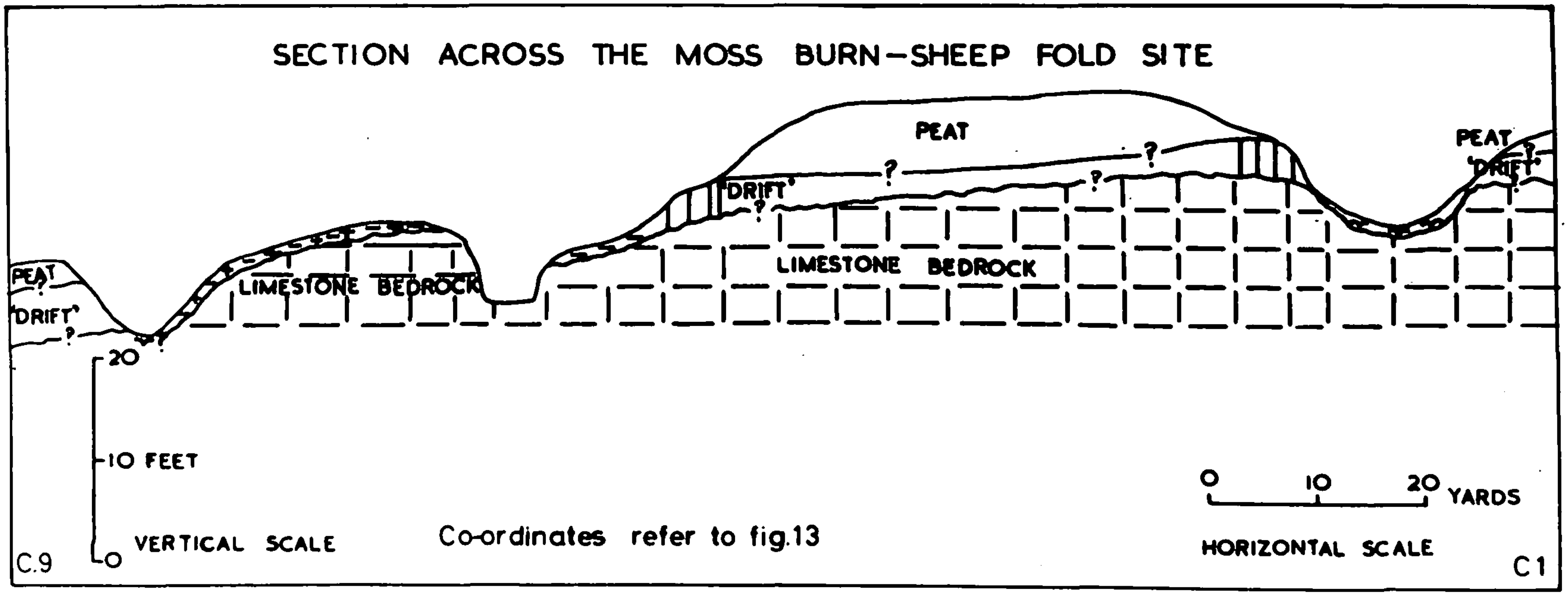

MOSS BURN—SHEEP FOLD SITE
0 10 20 YARDS
SCALE
N
SHEEP FOLD
Moss Burn
Moss Burn
R
R
I
H
G
F
E
D
C
B
A1
2
3
4
5
6
7
8
9

FIG. 13



SECTION ACROSS THE MOSS BURN-SHEEP FOLD SITE
PEAT
'DRIFT'
LIMESTONE BEDROCK
20
10 FEET
0
VERTICAL SCALE
Co-ordinates refer to fig.13
0 10 20 YARDS
HORIZONTAL SCALE
C.9
C1

FIG. 14

DIAGRAM OF THE MOSS BURN - FLUSH SITE

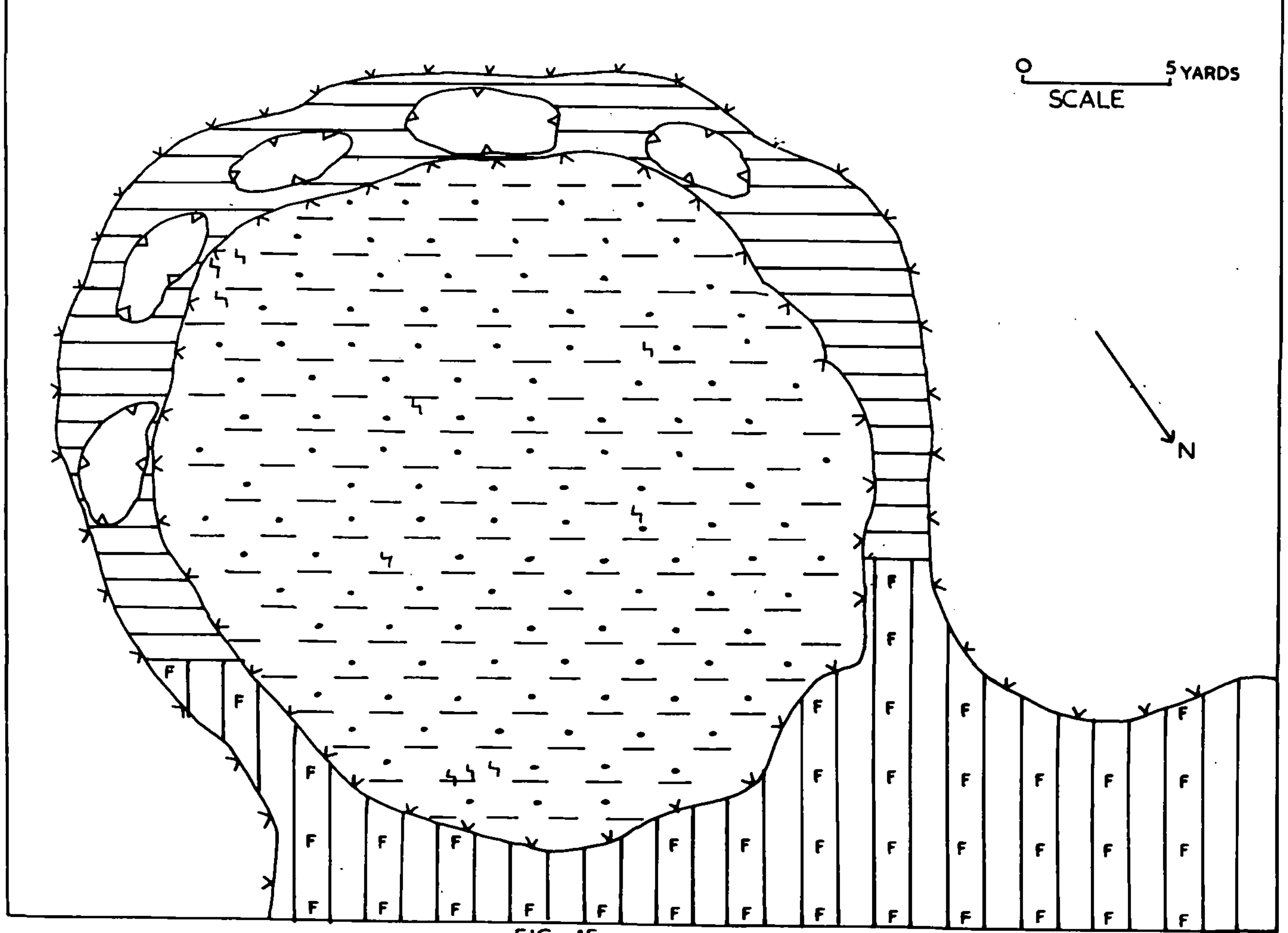


FIG. 15

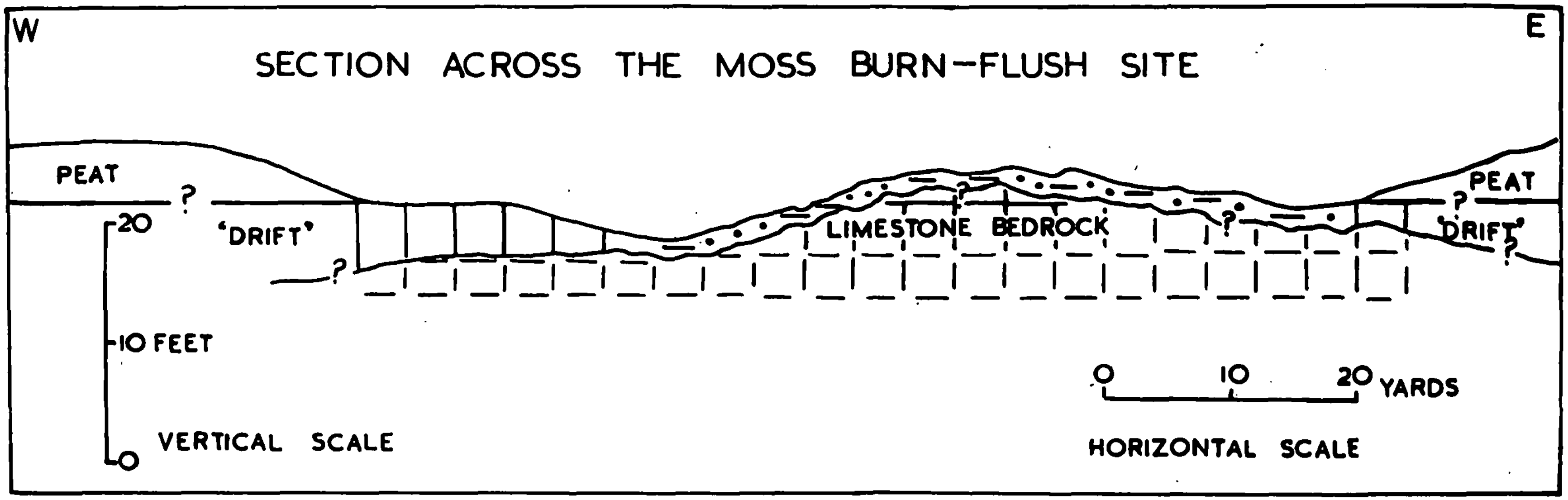

W
E
SECTION ACROSS THE MOSS BURN—FLUSH SITE
PEAT
'DRIFT'
LIMESTONE BEDROCK
PEAT
'DRIFT'
20
10 FEET
0
VERTICAL SCALE
0 10 20 YARDS
HORIZONTAL SCALE

FIG.16

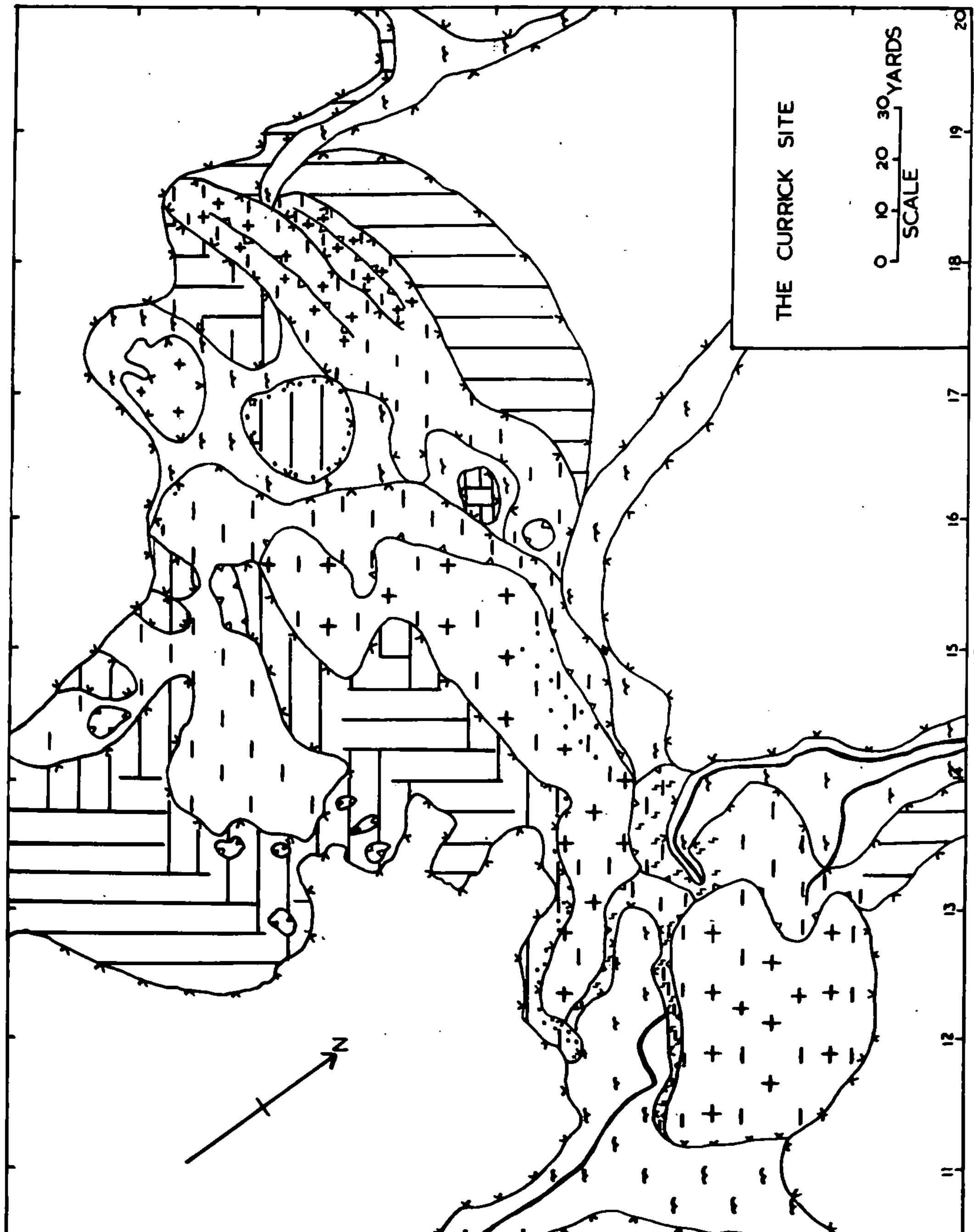
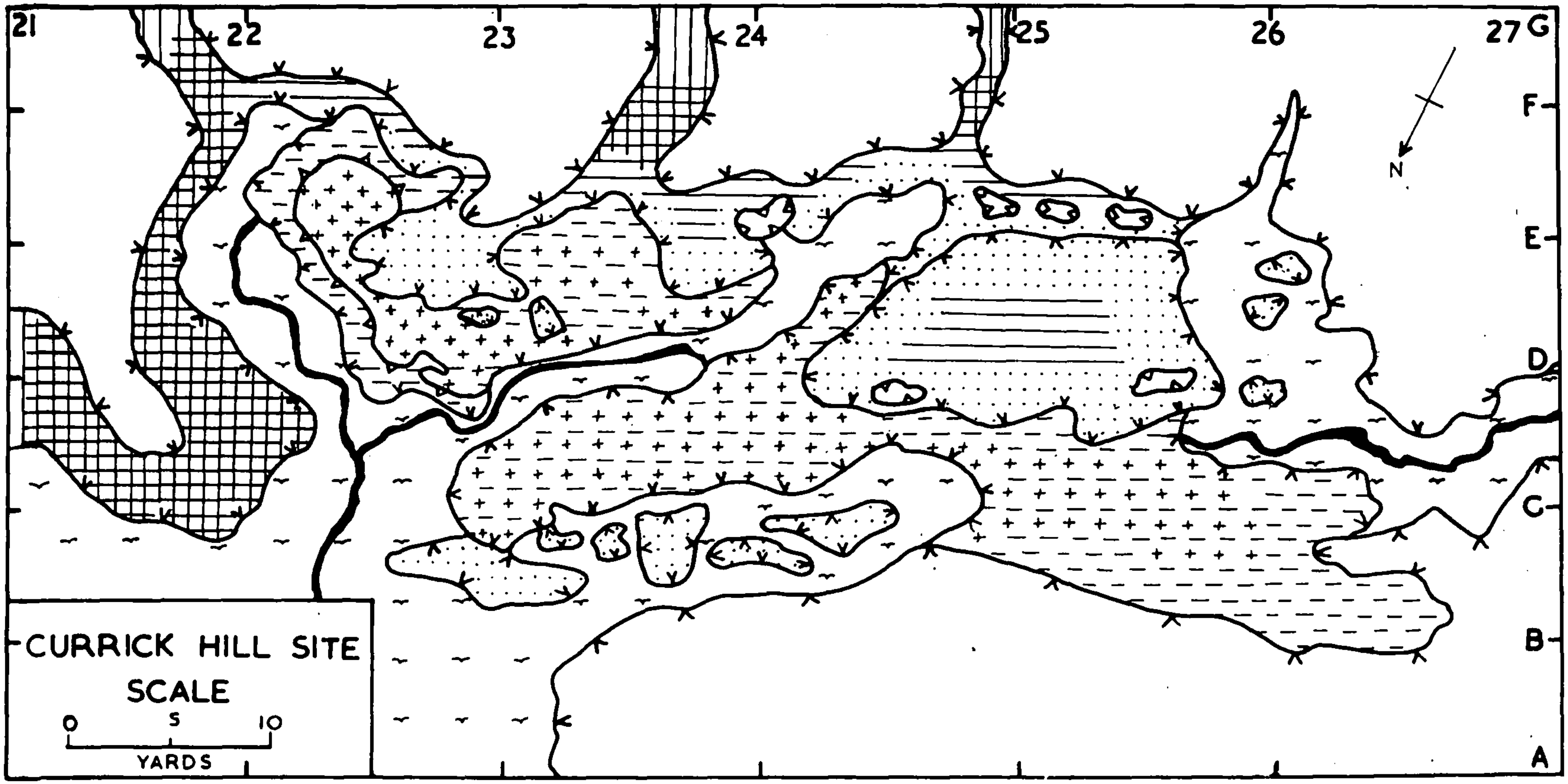

THE CURRICK SITE
0 10 20 30 YARDS
SCALE
N
10
11
12
13
14
15
16
17
18
19
20
A
B
C
D
E
F
G
H
I

FIG.17



21
22
23
24
25
26
27
G
F
E
D
C
B
A
N
CURRICK HILL SITE
SCALE
0
5
10
YARDS

FIG. 18

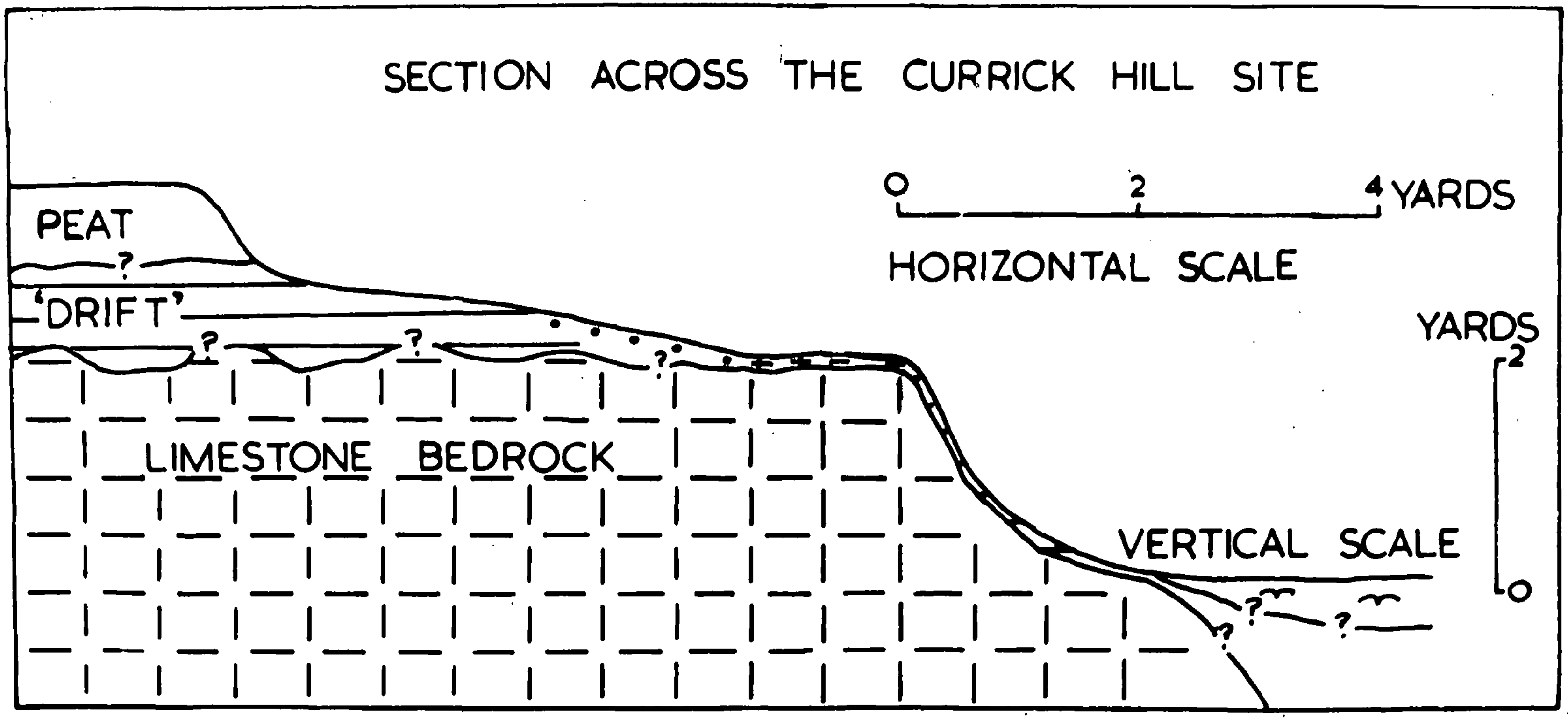

SECTION ACROSS THE CURRICK HILL SITE
PEAT
'DRIFT'
LIMESTONE BEDROCK
0 2 4 YARDS
HORIZONTAL SCALE
YARDS
2
0
VERTICAL SCALE

FIG.19

LIMESTONE GRASSLAND SITE NO. 5

0 10 YARDS
APPROX. SCALE

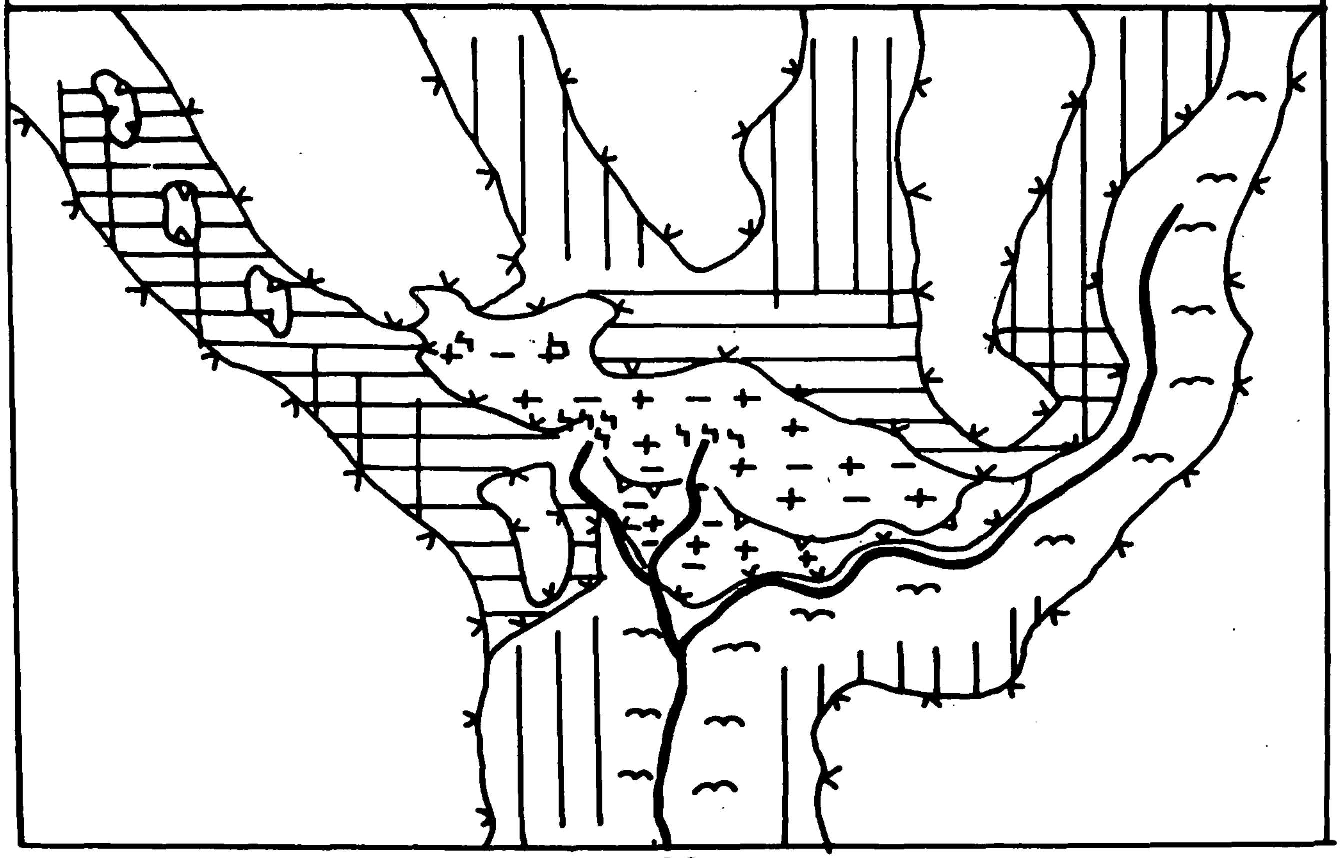


FIG. 20

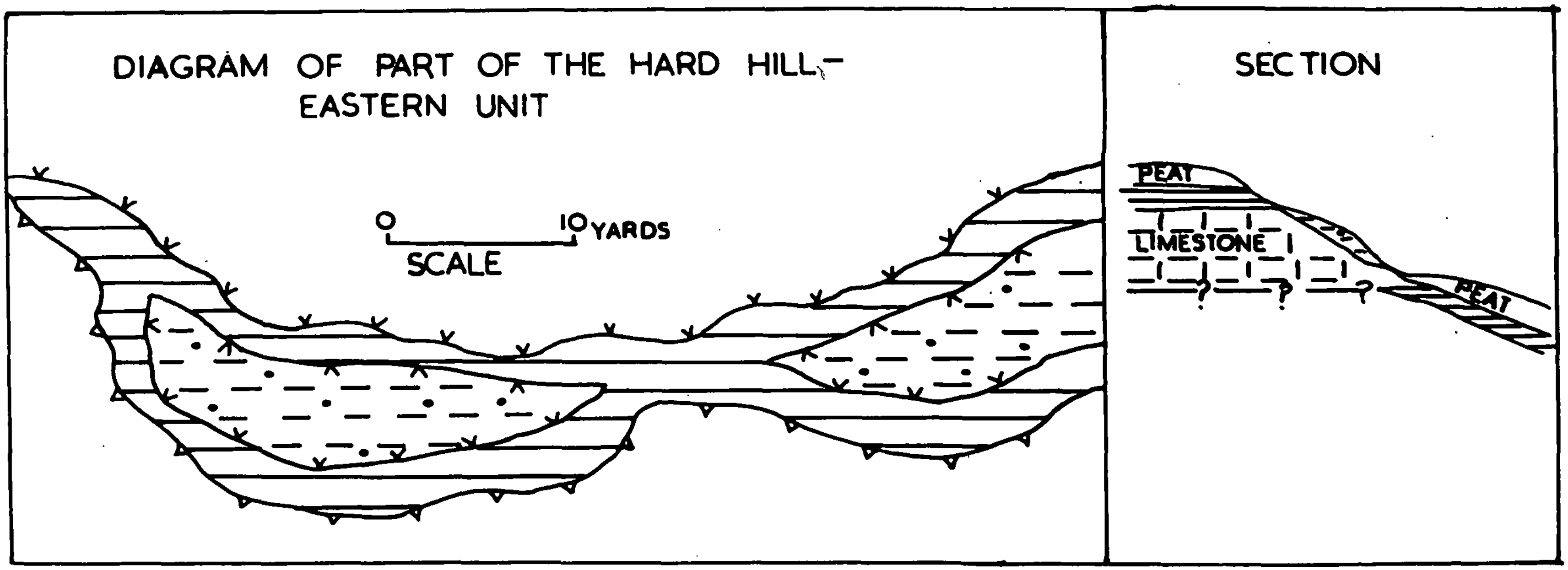
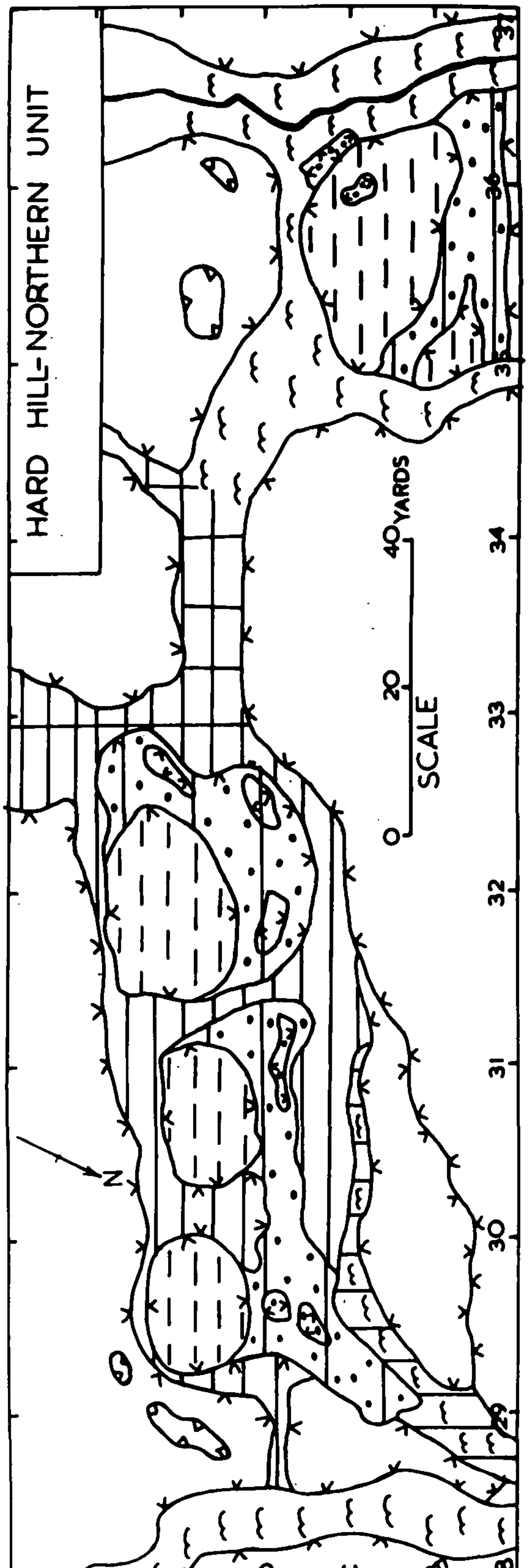


DIAGRAM OF PART OF THE HARD HILL-
EASTERN UNIT
0
10 YARDS
SCALE
SECTION
PEAT
LIMESTONE
PEAT

FIG. 21



HARD HILL-NORTHERN UNIT
SCALE
0
20
40 YARDS
N
G
F
E
D
C
B
A
28
29
30
31
32
33
34
35
36
37

FIG. 22

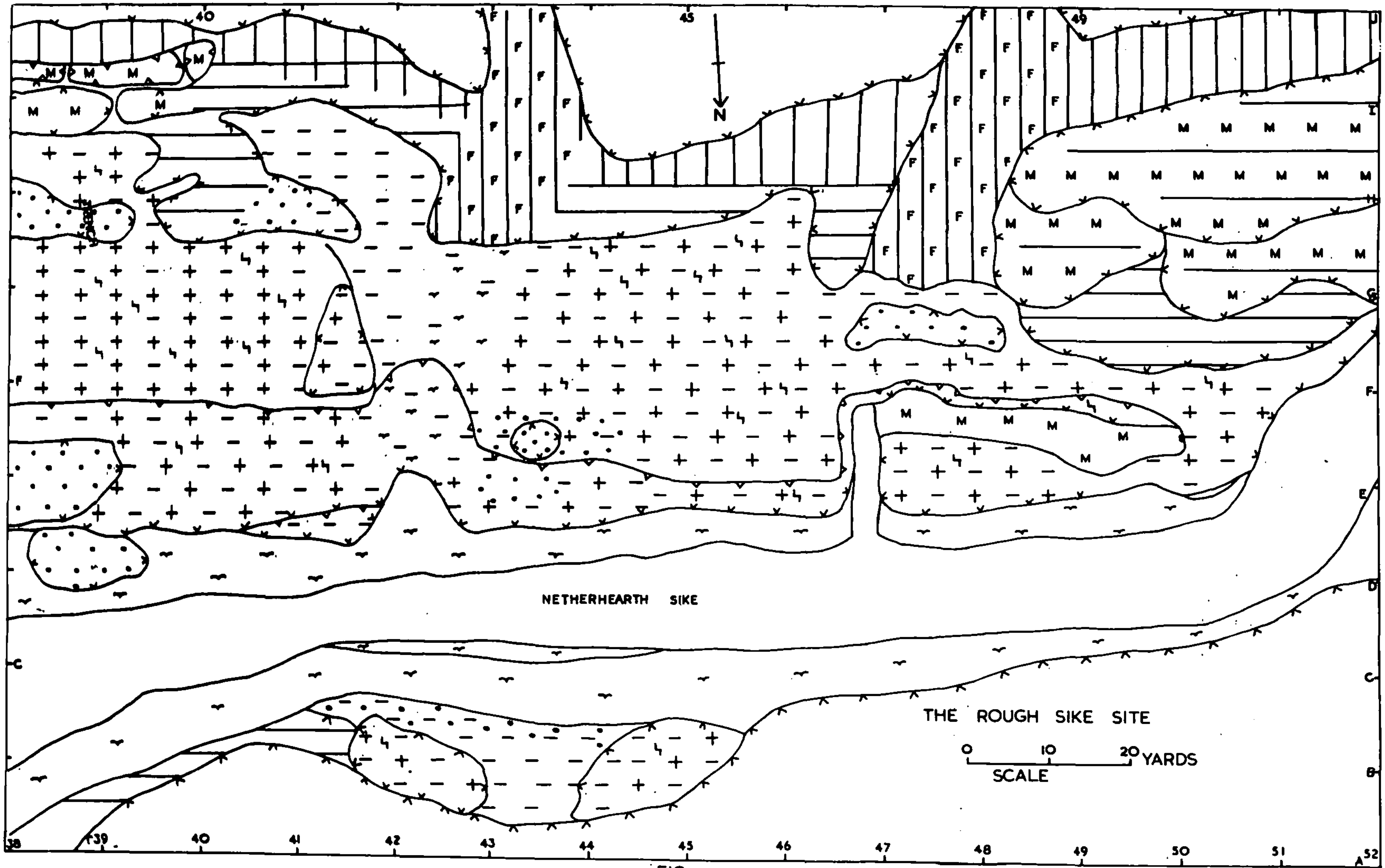


FIG. 23

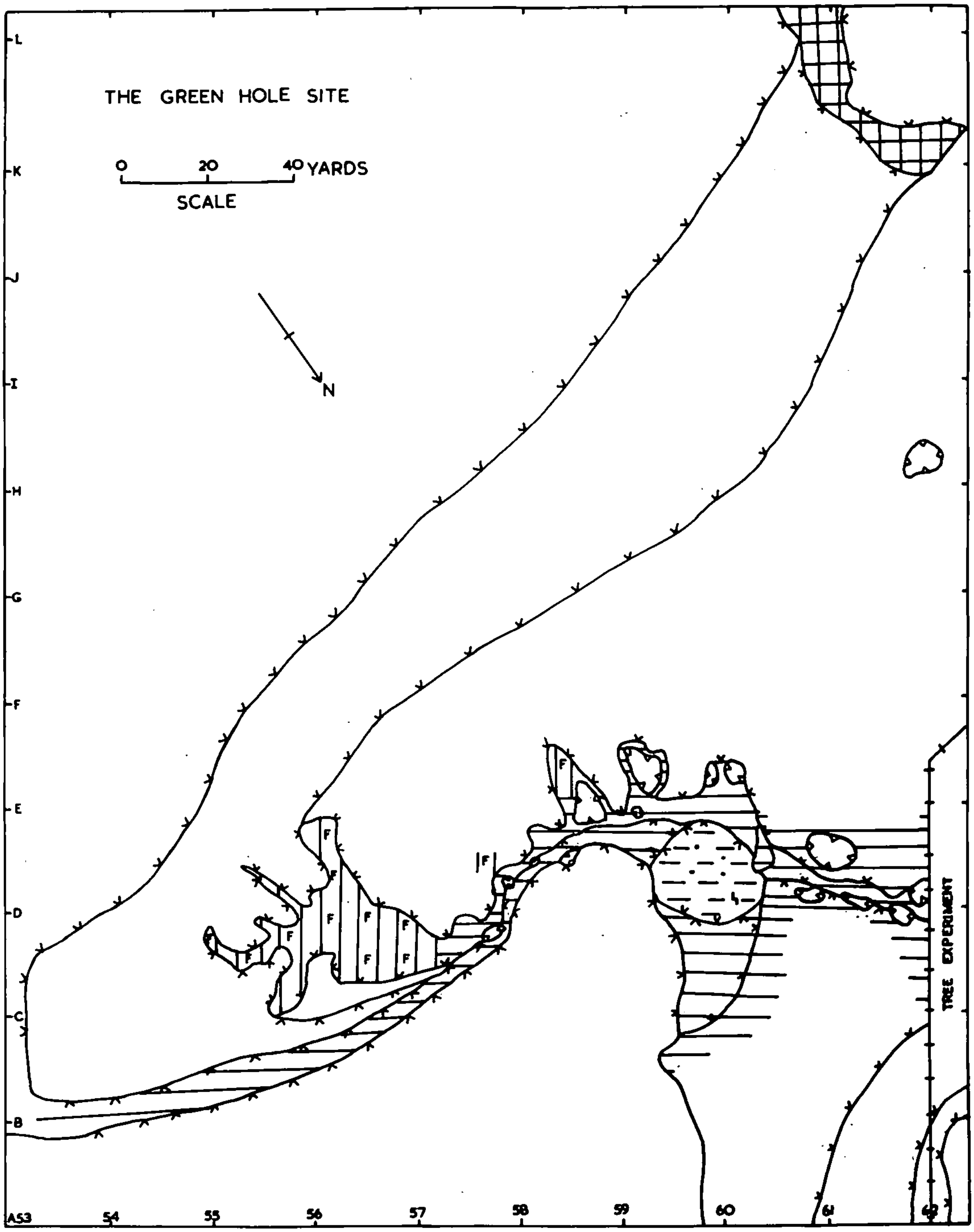

THE GREEN HOLE SITE
0 20 40 YARDS
SCALE
N
L
K
J
I
H
G
F
E
D
C
B
A53
54
55
56
57
58
59
60
61
62
F
TREE EXPERIMENT

FIG. 24

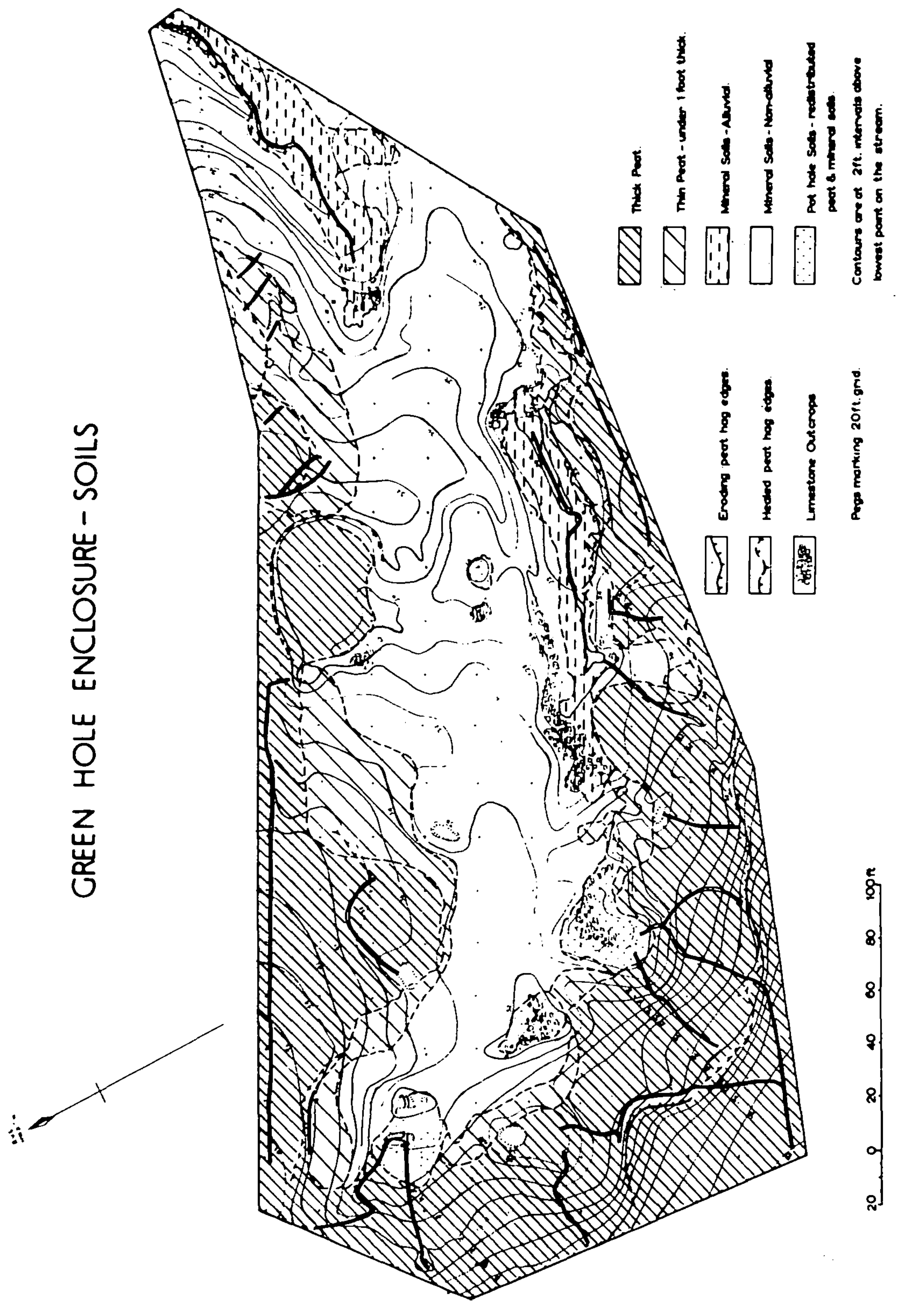

GREEN HOLE ENCLOSURE - SOILS
Thick Peat.
Thin Peat - under 1 foot thick.
Mineral Soils - Alluvial.
Mineral Soils - Non-alluvial.
Pot hole Soils - redistributed peat & mineral soils.
Contours are at 2ft. intervals above lowest point on the stream.
Eroding peat hag edges.
Healed peat hag edges.
Limestone Outcrops
Pegs marking 20ft. grid.
20 0 20 40 60 80 100 ft.

Fig. 25.

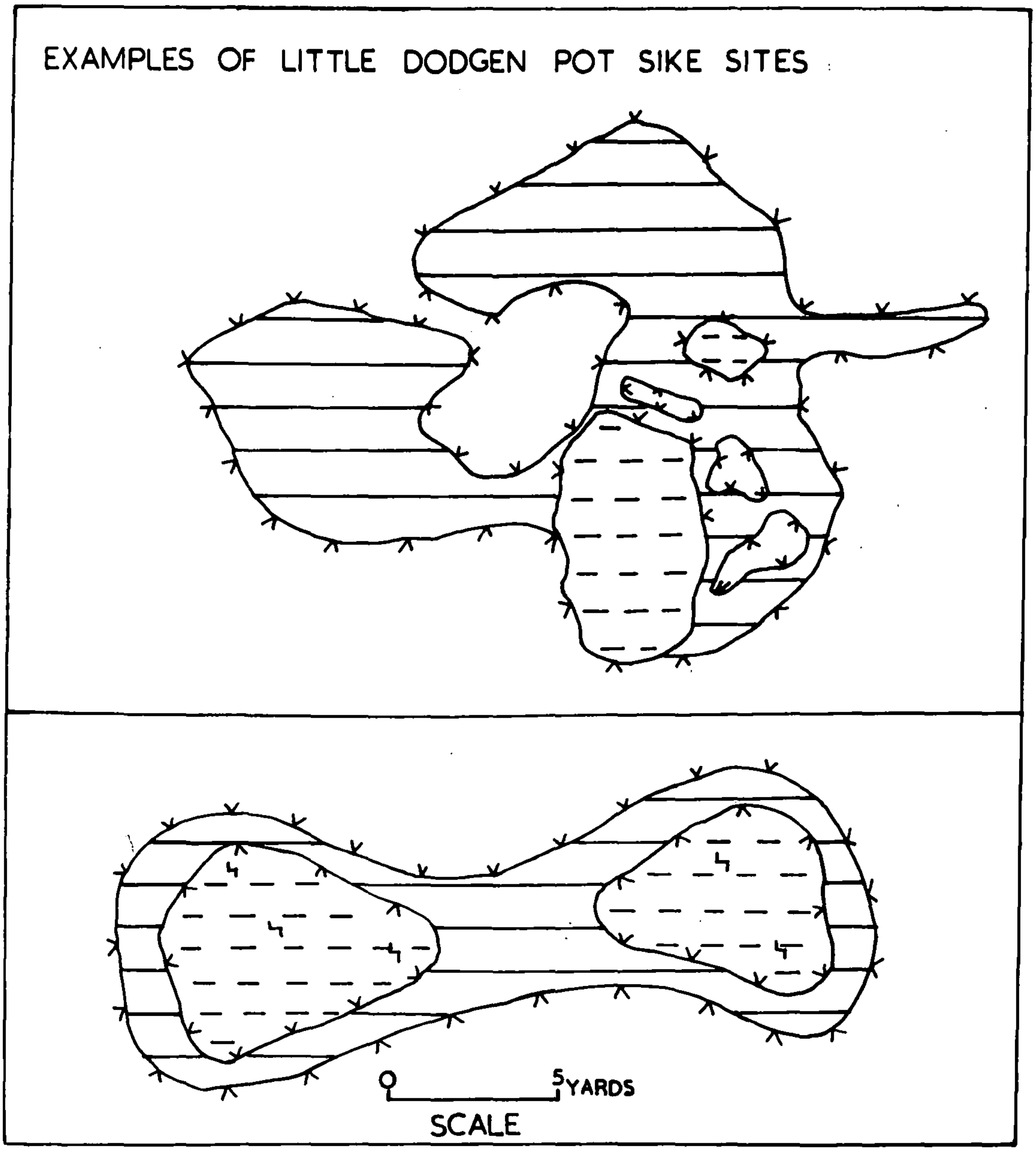
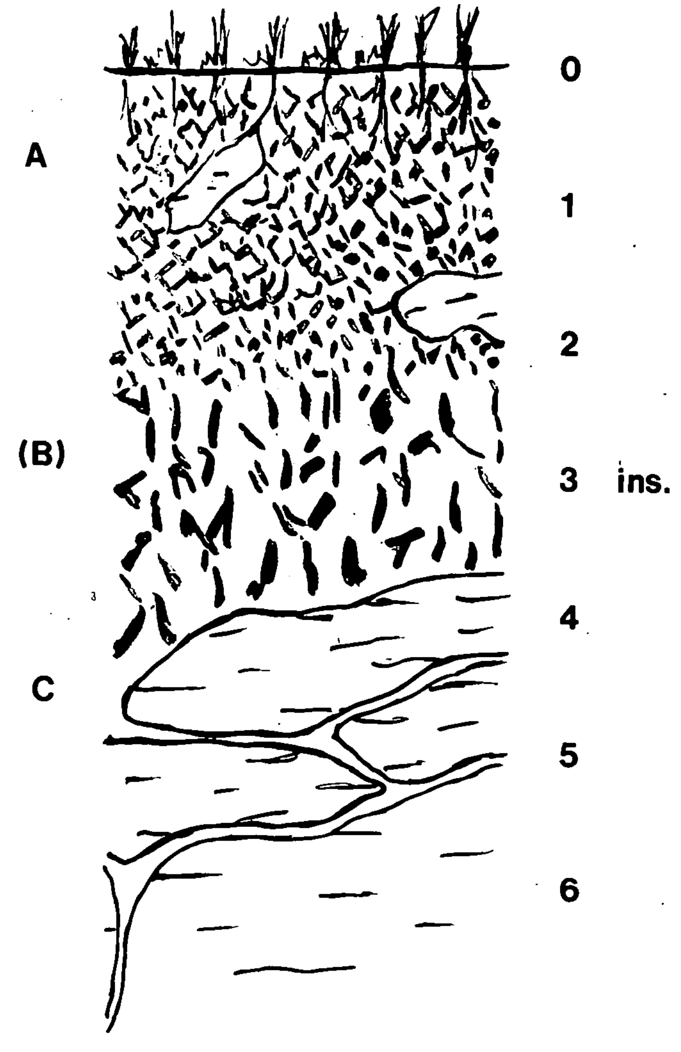


FIG. 26

RENDZINA

FIG. 27



BROWN CALCAREOUS
SOIL

FIG. 28

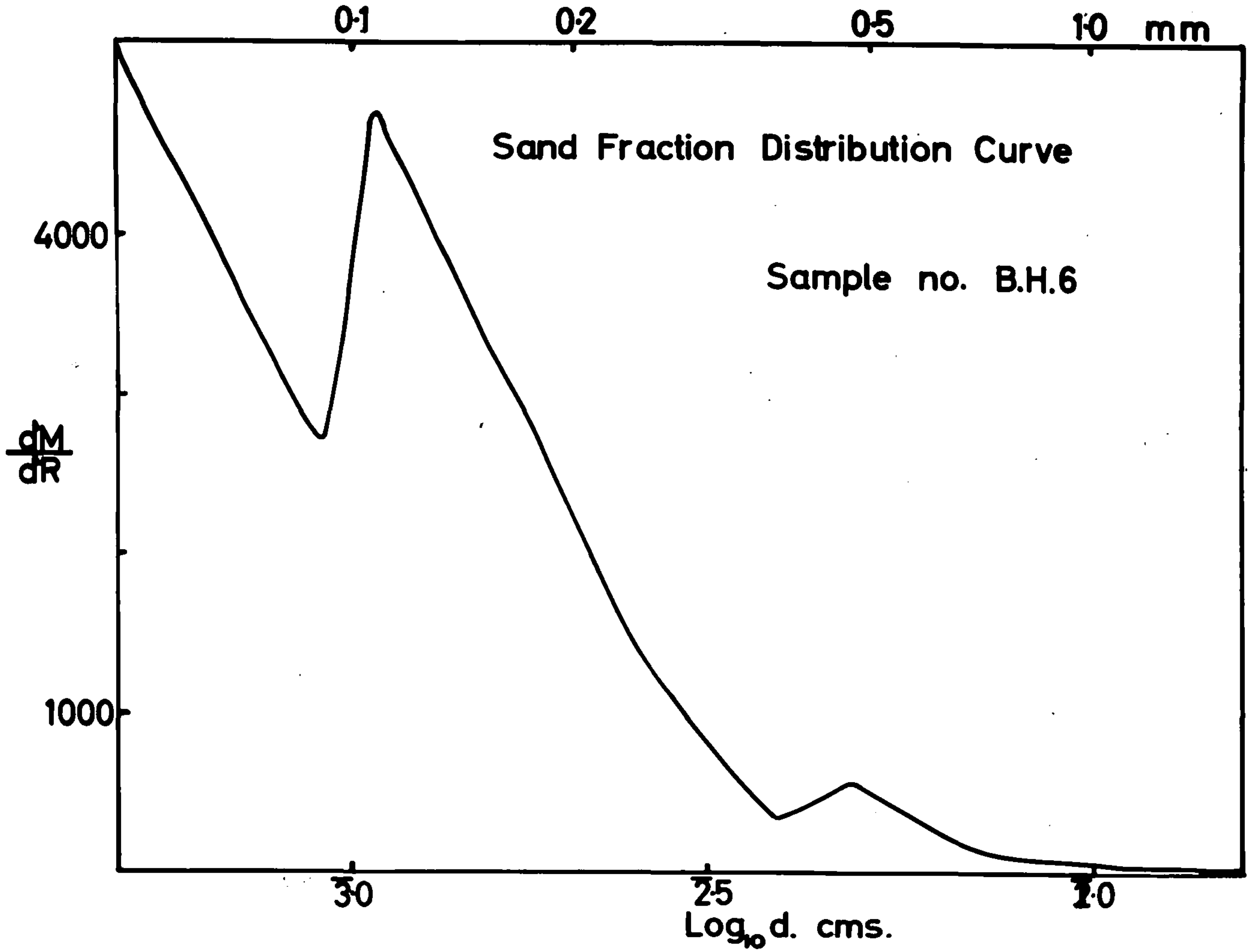
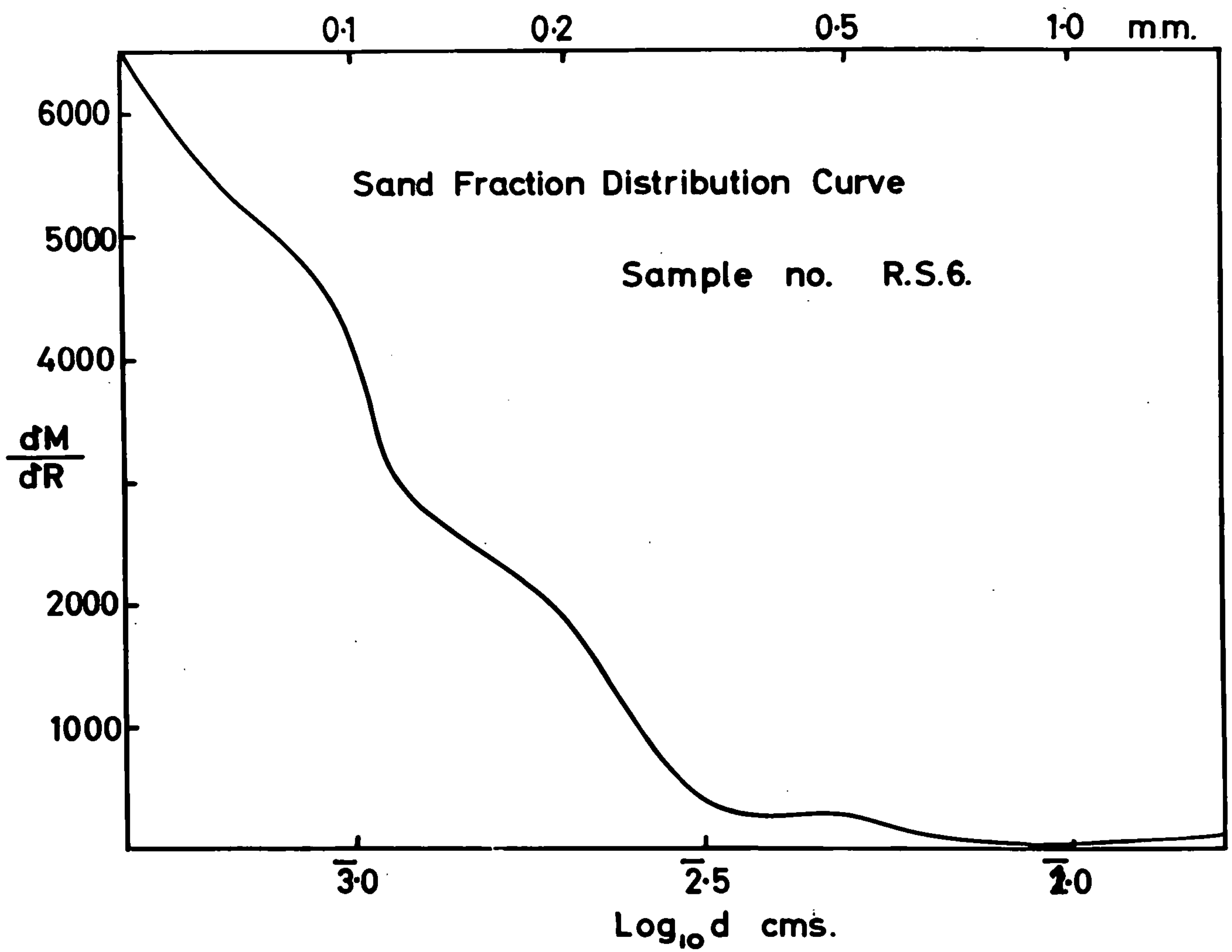

0·1
0·2
0·5
1·0 mm
Sand Fraction Distribution Curve
Sample no. B.H.6
4000
dM/dR
1000
3̄·0
2̄·5
2̄·0
Log₁₀ d. cms.

FIG. 29



0·1
0·2
0·5
1·0 mm.
6000
5000
4000
dM/dR
2000
1000
Sand Fraction Distribution Curve
Sample no. R.S.6.
$\bar{3}$·0
$\bar{2}$·5
$\bar{2}$·0
$Log_{10} d$ cms.

FIG. 30

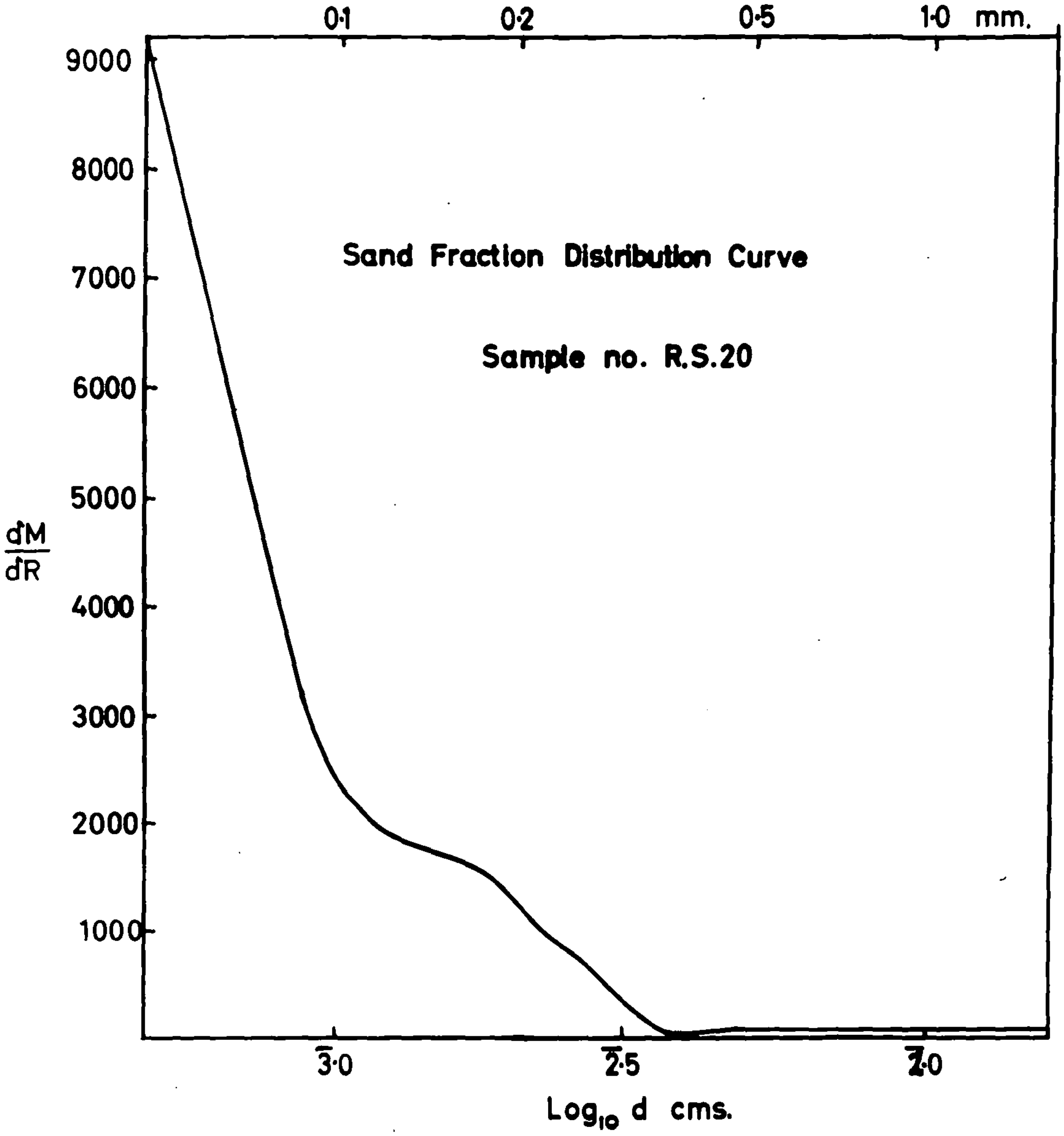

0·1
0·2
0·5
1·0 mm.
9000
8000
7000
6000
5000
4000
3000
2000
1000
dM/dR
Sand Fraction Distribution Curve
Sample no. R.S.20
$\bar{3}$·0
$\bar{2}$·5
$\bar{2}$·0
Log$_{10}$ d cms.

FIG. 31

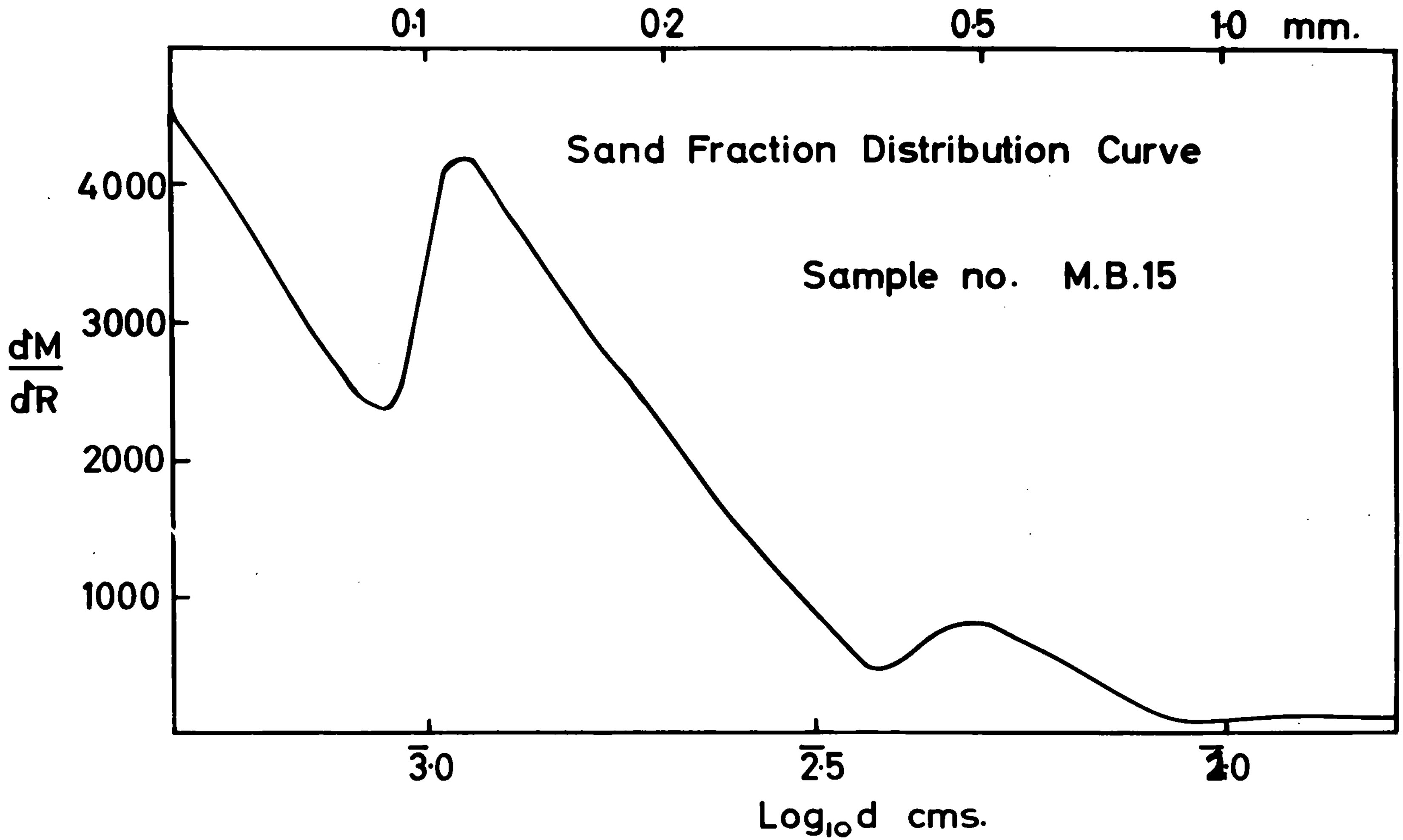
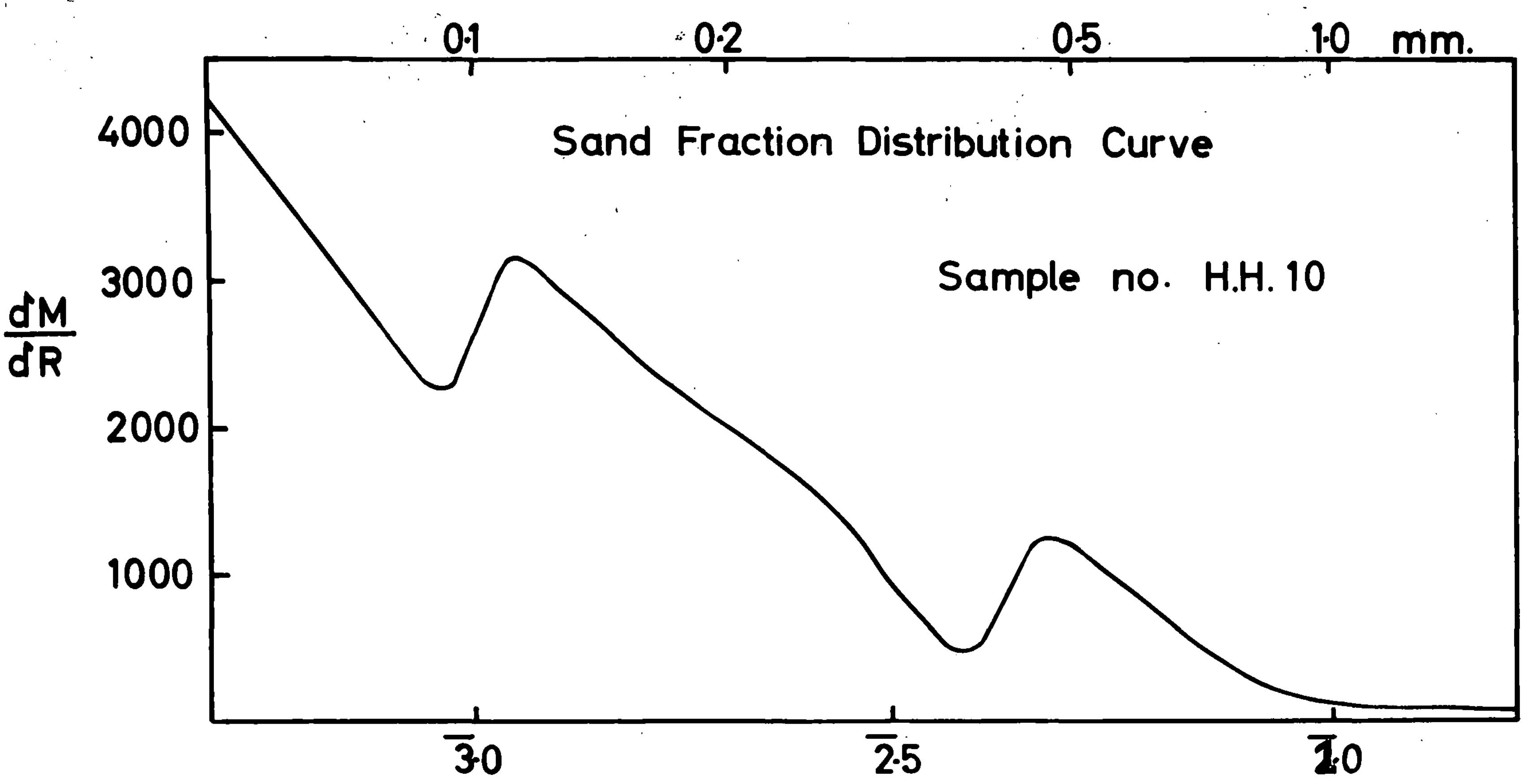

0·1
0·2
0·5
1·0 mm.
Sand Fraction Distribution Curve
Sample no. M.B.15
4000
3000
2000
1000
dM/dR
$\bar{3}$·0
$\bar{2}$·5
$\bar{2}$·0
Log$_{10}$d cms.

FIG. 32



0·1
0·2
0·5
1·0 mm.
Sand Fraction Distribution Curve
Sample no. H.H. 10
4000
3000
2000
1000
dM
dR
3·0
2·5
2·0
Log10d cms.

FIG. 33

VARIATION IN SOIL SUB-GROUP AND VARIOUS SOIL PROPERTIES WITH INCREASING DEPTH OF SUPERFICIAL COVER OVER LIMESTONE

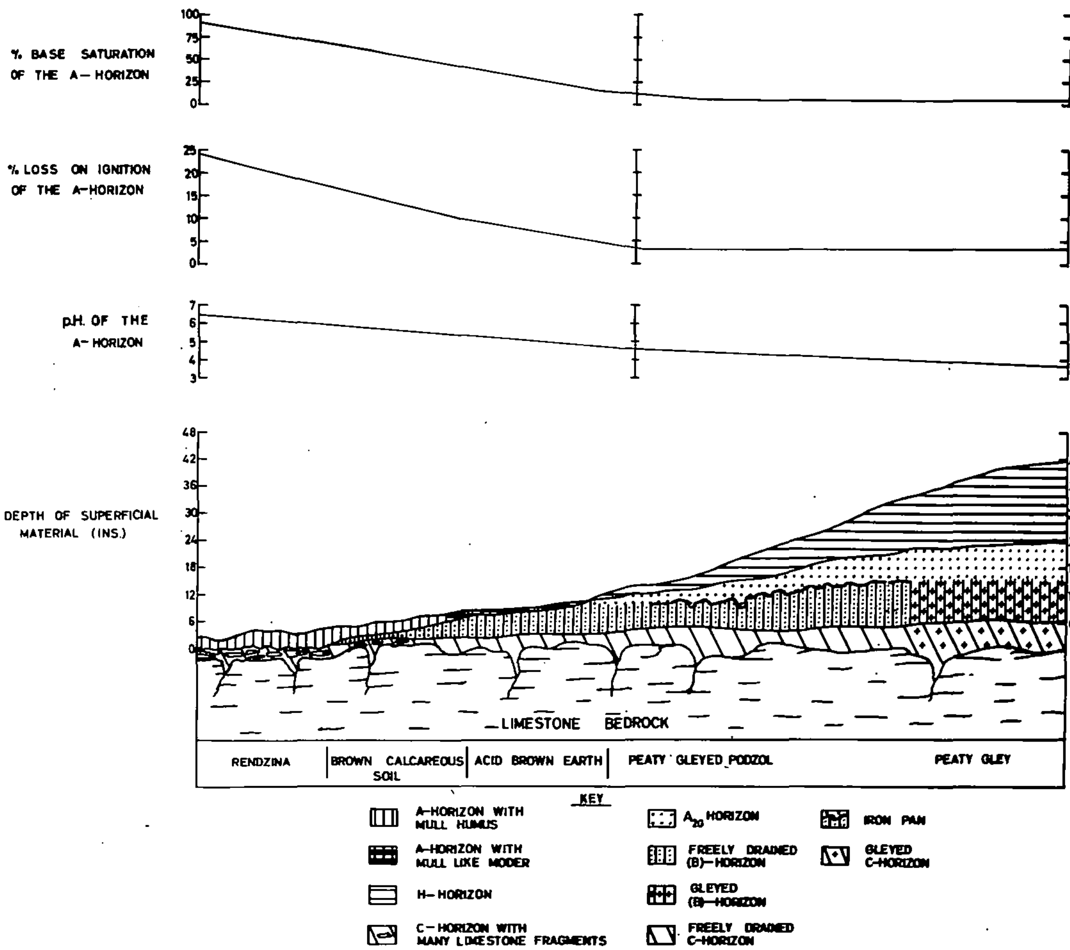


FIG. 34

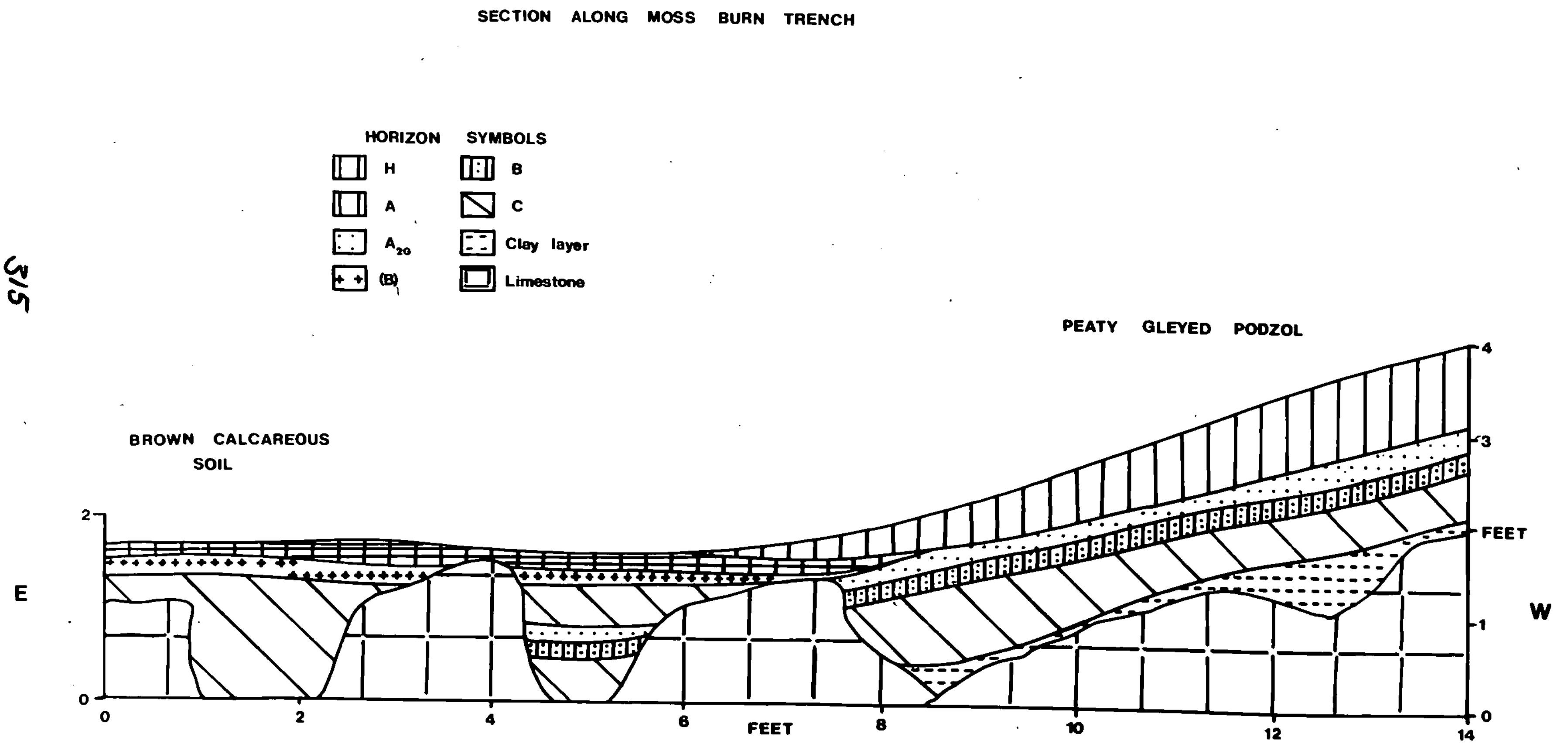

SECTION ALONG MOSS BURN TRENCH
HORIZON SYMBOLS
H
A
A_{2G}
(B)
B
C
Clay layer
Limestone
PEATY GLEYED PODZOL
BROWN CALCAREOUS SOIL
E
W
FEET
FEET
0
2
4
6
8
10
12
14
0
1
2
3
4

FIG. 36

HISTORY OF A LIMESTONE GRASSLAND SITE

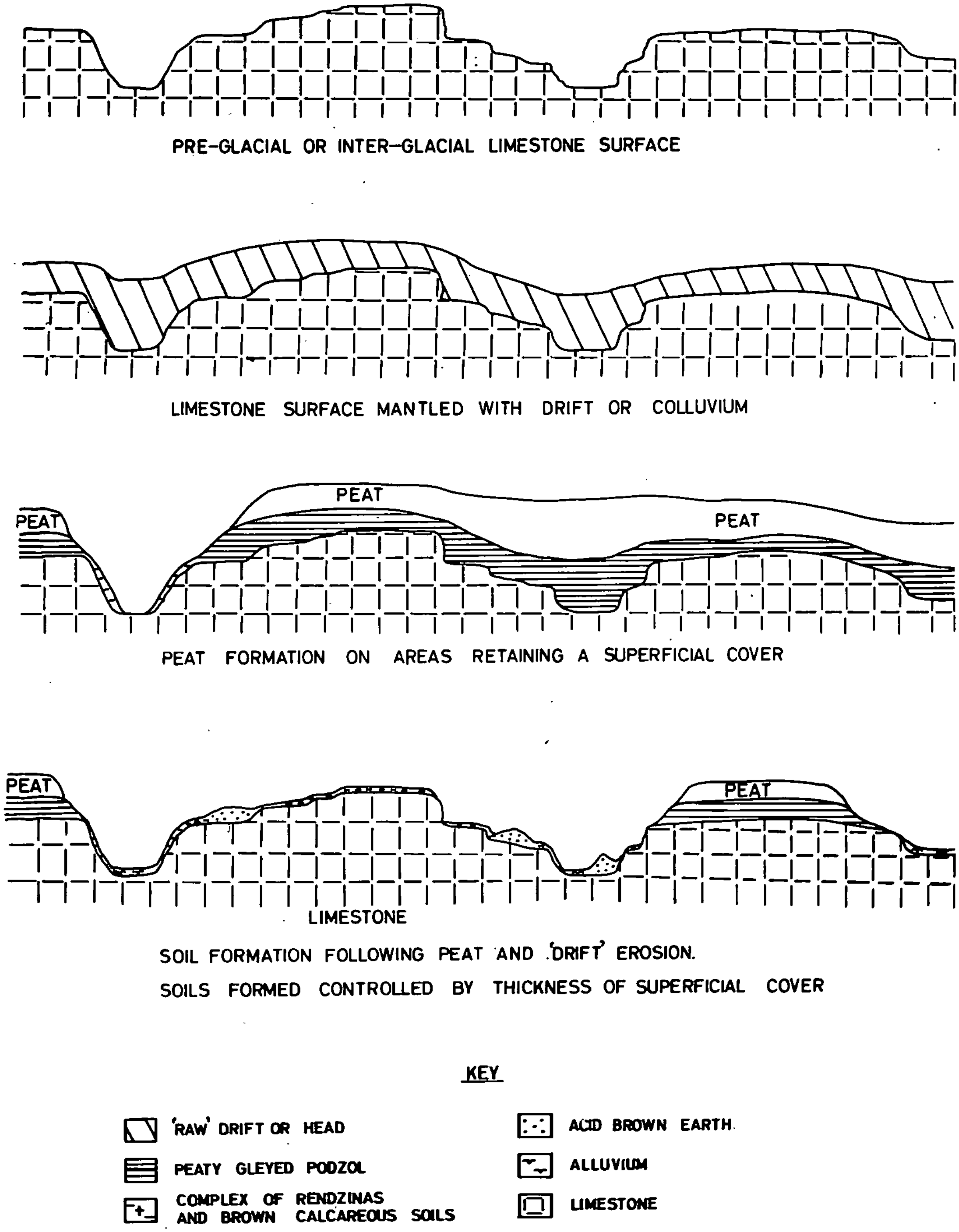


FIG. 37

PART III

STUDIES OF SOME OF THE SOIL SUB-GROUPS OF THE

MOOR HOUSE N.N.R. WITH PARTICULAR

REFERENCE TO THE ESCARPMENT.

CHAPTER 16

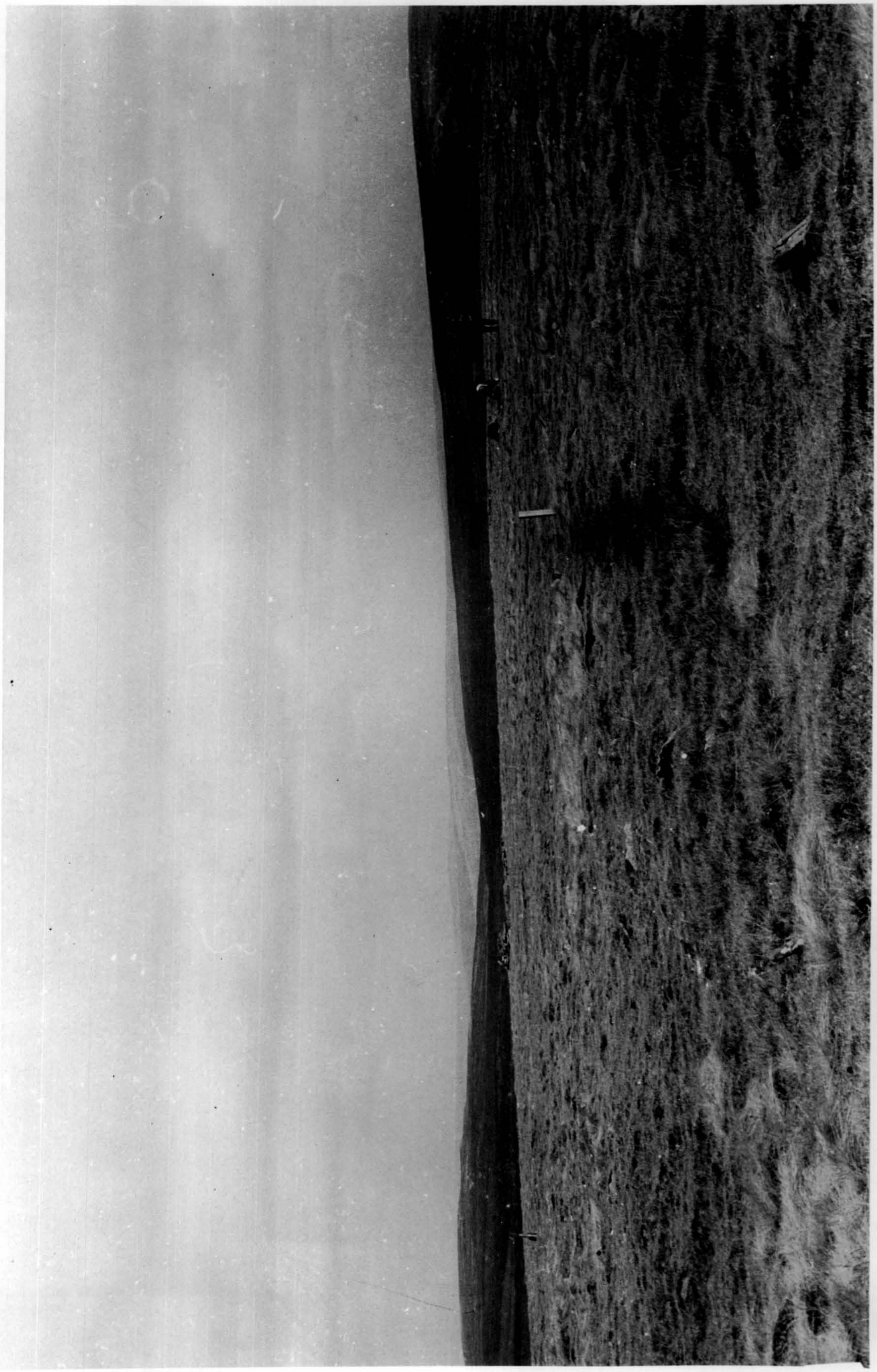
Humus Iron Podzols

16.1. Distribution and Site Characteristics of the Humus Iron Podzols.

The Fell Top Podzols of Johnson (Johnson and Dunham 1963), fig 11, are here referred to the humus iron podzol sub-group though the term used by Johnson is descriptive of their location. They are found on the summits of Cross Fell, Great Dun Fell, Little Dun Fell, Knock Fell and Hard Hill. In the first four cases they are located on relatively flat summit areas which drop away on all sides, but on Hard Hill they are found on a level or slightly sloping terrace in the general east north easterly slope of Hard Ridge (Plate 50). The surface of the sites is very characteristic and striking. It is dotted with a very large number of boulders which project through the surface and the vegetation cover. (Plates 50 and 51). These boulders are usually slab like and are derived from the underlying sandstone bedrock. They are inclined at various angles to the vertical and are direct indications of the intense solifluxion activity which has affected the sites. Although having the same general profile characteristics they differ in detail, the soils on Hard Hill and Cross Fell are very similar and those on the Dun Fells and Knock Fell are also fairly similar.

The Hard Hill and Cross Fell sites are rather more extensive than the other two and differ from the other areas in being closely associated with blanket peat deposits or remnants of a blanket peat cover. A great deal of attention has been focussed on the Hard Hill site and an exclosure has been maintained there for over ten years. The first warden of the Moorhouse Field Station, the late K.F. Park, carried out some work on the soils of the site and some of his results and comments are incorporated here (This work is also found in "Moor House Reserve Records Volume VIIa"). The site forms a bench like break in the general easterly slope of Hard Ridge (Plate 50).

Plate 50. The bench on Hard Ridge on which humus iron podzols are found : sandstone blocks can be seen protruding through the surface.



The area itself is almost level, the slope being between one and two degrees to the north. This bench is due to the outcrop of the Quarry Hazle, one of the thicker Yoredale sandstones, at 2250 ft. O.D. which is gently dipping to the east. On the east the area is truncated by a marked change of slope probably associated with the fault which crosses Hard Hill. From this change of slope the ground drops down to another bench like area which contains thick eroding peat haggs. The slope between these two benches carries alternate patches of blanket peat and Nardetum sub-alpinum on a peaty gleyed podzol. To the west a blanket peat cover comes in fairly sharply and thickens upslope although it never reaches any great thickness. The bench like area is also terminated by a fairly marked break of slope to the south but before this break of slope the grassland vegetation grades into blanket peat. To the north and north west the slope steepens more gradually and as it does a layer of blanket peat comes in and thickens.

The whole of the bench like area of the Hard Hill humus iron podzol site may have been covered by peat at some time in the past. It is virtually surrounded by blanket peat and although some of this develops after a break of slope some is found on the bench itself. The site would be more freely draining than those covered by a true drift cover but this factor alone would be unlikely to prevent peat development.

The vegetation of the peat free area is shown on the vegetation map of Eddy and Welch (1965), fig 9, as Festucetum. In detail the Hard Hill site is a mozaic of small areas with the dominant species varying quite rapidly. To quote from Park (Reserve Records Vol. VIIa), "The vegetation is variously dominated by Festuca ovina, Nardus stricta and Juncus squarrosus. There are three main types of Festucetum: areas of Festuca with Carex bigelowii and relatively few lichens, areas of Festuca with lichens and little or no Carex, and areas of Festuca with Polytrichum commune. About 4.0 species occur per point quadrat. Areas of Nardus dominated turf (3.0 species per quadrat) and patches of

Plate 51. East of the summit of Little Dun Fell showing sandstone boulders through the soil cover.

Juncus (4.1 species per quadrat) occur in the background of Festuca".

Eddy, Welch and Rawes (1968) suggest that this type of vegetation has been derived by grazing from a community dominated by Vaccinium. Park (Reserve Records Vol. VIIa) suggests that the vegetation mozaic on Hard Hill may be due to "over grazing and variations in the drift cover".

The summit area of Cross Fell which carries the humus iron podzol soil type is much more extensive than the other summit areas involved. It is a plateau and terminates on all sides in marked breaks of slope. The cover of superficial material which blankets the plateau rests on the Dun Fell sandstone. The area involved is really a complex of, (a) Festucetum on an humus iron podzol, (b) shallow peat (Mostly less than 15" minimum for blanket peat) with a humus iron podzol below, and, (c) areas with a very sparse vegetation, and virtually a stone pavement, with the same soil type below.

The surface is again dotted with a large number of slabs of sandstone which project through the soil cover at angles close to the vertical. Stone polygons are also developed over a large part of the surface and where there is a Festucetum cover they produce a hummock and hollow surface. The surface has obviously suffered intense solifluxion activity in the past and may well be being affected by less intense activity today, especially during bad winters. The way that the same soil type is found beneath the three types of surface infers that the same soil forming conditions were once prevalent over the whole area. The stone pavement found on the bare soil is present in the other types of surface but in the other cases it is just below the soil surface. It is easy to imagine the three surfaces as different stages of erosion with a thin peaty cover formerly extending over the whole of the summit plateau. As this peaty cover is eroded away some areas become stabilised at the mineral soil surface by a Festucetum community but in other cases erosion continues and exposes the stone pavement normally just below the surface of the mineral soil.

The summits of Great Dun Fell and Little Dun Fell are relatively flat, but by no means as flat as the summit plateau of Cross Fell, and drop away very steeply on all sides. (Plate 5). As with Cross Fell the superficial material rests on the Dun Fell Sandstone. The superficial cover on the slopes away from the summits is highly unstable and continually moving downslope, the summit area is so restricted that it is likely to be affected by this instability. Although the summits are almost flat, a slope of 2^{o} or 3^{o} is usually present and this is sufficient for movement under periglacial conditions and perhaps in bad winters at the present.

On the slopes away from the summits stone stipes are developed and stone polygons, not as well developed as those on Cross Fell, are developed on the summits and give a marked micro topography. Park (Reserve Records) describes the vegetation of the summit of Little Dun Fell as follows: "The vegetation may be described as sub-alpine grass-heath and consists of a mozaic of communities. At the north-western and south eastern ends the dominants are <u>Festuca spp</u>., <u>Deschampsia flexuosa</u>, <u>Carex bigelowii</u> and <u>Vaccinium spp</u>. Small bare patches occur, some of them recolonising with <u>Festuca</u>, <u>Vaccinium</u> and various lichens. Other parts of the plateau support a well marked mozaic; areas dominated by <u>Festuca</u> alternate with areas codominated by <u>Rhacomitrium canescens</u>, <u>Festuca</u> and <u>Carex bigolowii</u>. Locally bryophytes occur in elongate patches; these seem to correspond to areas with slightly impeded drainage". Perhaps the most important characteristics of these sites is the instability of any superficial material.

The Knock Fell area is rather different from the summits just described. The underlying sandstone, the Coal Sills, forms a slight topographic dome rising from the relatively flat Knock ridge. The central area of the dome has a cover of heavy sandstone debris with bare soil, <u>Festucetum</u> or thin peaty material developed patchily. Many of the sandstone blocks are in near vertical positions. In places the blockfield is so heavy that a stone pavement is produced. The north and eastern slopes of the dome are occupied by a <u>Festucetum</u> and the south by a Sphagneto-Caricetum alpinum (Eddy and Welch 1965). To the west the blockfield gives way to Juncetum squarrosum sub alpinum. The humus iron podzol merges at the margins of the dome with a peaty gleyed podzol - peaty gley soil complex. Superficial material on the top of the dome would be unstable but it is unlikely that it remained without a shallow peaty surface cover in the period of maximum peat expansion. A puzzling feature of the part of Knock Fell occupied by the humus iron podzols is why this small area projects above the main part of the ridge which is almost wholly underlain by the Coal Sills Sandstones. It is also puzzling why the rest of the ridge carries a peaty gleyed podzol - peaty gley complex and not a humus iron podzol. Factors important in limiting the distribution of this soil sub-group are microtopography and the presence of transported clay and silt rich superficial material.

The humus iron podzols are developed on the low convex domed region which has negligible transported superficial cover and better drainage than the surrounding contaminated area where peaty gleyed podzols and peaty gleys are found.

16.2. Morphology of the Humus Iron Podzol (Plates 52 - 55).

Two variants of the iron humus podzol are found and they will be distinguished as a deep phase and a shallow phase. The shallow phase is similar to a podzol ranker. The deep phase (Profile 15) is developed on Hard Hill and Cross Fell and the shallow phase (Profile 16) on Great and Little Dun Fell. The striking feature of the profiles is the B_{1H} horizon which is always developed, although it is more marked in the deep phase. A shallow H horizon of 2-3 inches is present and consists of mor humus. The boundary between this and the mineral soil is sharp, although, inevitably, a few bleached quartz grains are found in the lower part of the H horizon. The underlying A_2 horizon is much more clearly marked in the deep phase and consists of grey brown

Plate 52. Humus iron podzol on Hard Hill. Profile 15 H.I.P.

bleached loamy sand and is 2-3 inches deep in the deep phase. In the shallow phase the horizon is not quite so deep and the grey colouration is not quite so marked. The B_{1H} horizon is very marked in the deep phase, is a black colour and is about 2" thick (Plates 52-55). Examination of the material beneath the microscope shows it to be the same loamy sand as above and below but each grain is coated with organic material. There is no cementation of the horizon. The shallow phase once again has a shallower representative of this horizon which is also less distinct, mainly because the upper and lower boundaries of the horizon are not so sharp.

This upper portion of the profile is always extremely stony (Plates 52 and 53) and often the H/A_2 junction is almost a continuous pavement of sandstone blocks with the near vertical blocks projecting through. In the deep phase, once this upper stony layer has been penetrated the next three feet or so, of material are virtually stone free. This is particularly marked on Cross Fell but rather less so on Hard Hill. In the shallow phase the extreme stoniness persists until the in situ bedding planes of the sandstone are encountered.

The B_2 horizon is once again much better defined in the deeper phase than in the shallow phase. In the deep phase the upper boundary is sharp but the lower one is rather diffuse or merging whereas in the shallow phase the upper boundary is diffuse and the lower merging. The horizon is 4" - 6" deep in the deep phase and 1" - 2" in the shallow phase. The horizon colour is usually a strong brown colour and passes downwards into a yellow brown or brown yellow.

In the shallow phase the B_2 passes fairly rapidly into highly disturbed bedrock which then becomes less and less disturbed with depth. The undisturbed bedrock is still at a considerable depth and was found at 9 ft. in the deep section reported by Johnson (Johnson and Dunham 1963). In the deeper phase a considerable depth of completely disintegrated material i.e. sandy loam, plus stones, may exist.

Plate 53. Humus iron podzol, deep phase, on Cross Fell. The stony nature of the surface horizon is clearly seen.

Undisturbed bedrock was not found in the deeper phases examined and profiles were taken to some four feet.

The lower part of the profile, i.e. below the B_2 horizon, shows a platey structure. This is very marked in the deeper phase but, although present, not terribly clear in the shallow phase. There is a marked increase in fines which parallels the incoming of the platey structure. The upper part of the profile is structureless.

Accumulations of manganese are also common in the lower part of the profile and usually produce a black speckling. Once again this effect is most marked in the deep phase, especially on Cross Fell.

In the deeper phase the lower part of the profile often has a patchy colouring with areas of the yellow brown of the overlying material and others of a grey brown colour. This colour variation may be as a small mottling or as patches several inches across. It is perhaps significant that many of the Yoredale sandstones when encountered away from the surface, e.g. in boreholes, have a grey colouration. The mottling here may be the patchy oxidation and alteration of relatively fresh parent material to give the yellow or brownish colour usually produced when these grey sandstones are exposed to the atmosphere.

Both phases of this soil type are extremely acid with the pH at the surface a maximum of 5.0 but more commonly 4 - 4.4. The pH does not vary much down the profile and was never found to rise above 5, it usually varied between 4.4 and 4.8. The surface horizons are extremely heavily leached and for the Hard Hill site the percentage base saturation of these horizons was always less than 5%. It is worth mentioning, that chemically the B_{1H} seems to be part of the illuvial horizon as the iron content reaches its lowest in this horizon (Results to profile 15 and 16). The writer hopes to investigate this further at some later date.

This is a very acid soil type developing on a base poor, siliceous parent material. In the deep phase the horizons are fairly well differentiated, although the B_2 is sometimes difficult to distinguish, and indicate fairly stable soil conditions for a reasonable period of time. These soil conditions need not necessarily be those extant at the present. The shallow phase shows a much poorer development with poor separation of horizons so that in some cases the A_2 is indistinguishable. This can be illustrated by quoting one of Park's (Reserve Records) profile descriptions for Little Dun Fell in which he does not distinguish an A_2. The difference in the two phases may be due to one of, or a combination of, several factors, e.g. difference in parent material, difference in site, difference in period of soil formation.

The parent materials of the soils will now be briefly examined. The soils on Hard Hill and Great Dun Fell were used for this work and so care must be taken if the results are extrapolated to the other sites. During the digging of the pits on Hard Hill no stones other than sandstone were found although Park (Reserve Records) reports finding one piece of limestone. There were many fragments in 2 m.m. - 2 cm. size range but in all horizons these proved to be either quartz fragments or small fragments of sandstone, plus, in the B_2 horizon, a few iron concretions and, lower down, a few manganese concretions. The high sand content throughout the profile implies derivation from a sandstone or preferential sorting of sand. It would seem to rule out a drift or aeolian origin. Examination of the fine sand fraction by Bullock's method (p. 123) shows a completely different distribution to the other materials examined in that there is a median concentration as opposed to one at the fine end of the fraction (Fig. 38). The same distribution was shown by the fine sand fraction of all horizons and also by the fine sand fraction of the Quarry Hazle sandstone. Samples of the sandstone were examined in thin section and the long axes of grains measured.

Examination of the clay fraction showed it to be composed of quartz and muscovite. The muscovite gave sharp peaks which is rare with the clay minerals from the drift or colluvial material. The peaks also increased in size and sharpness down the profile indicating an increase in quantity of the muscovite and also increasing freshness (Fig.39). These are the kind of results one expects from an <u>in situ</u>

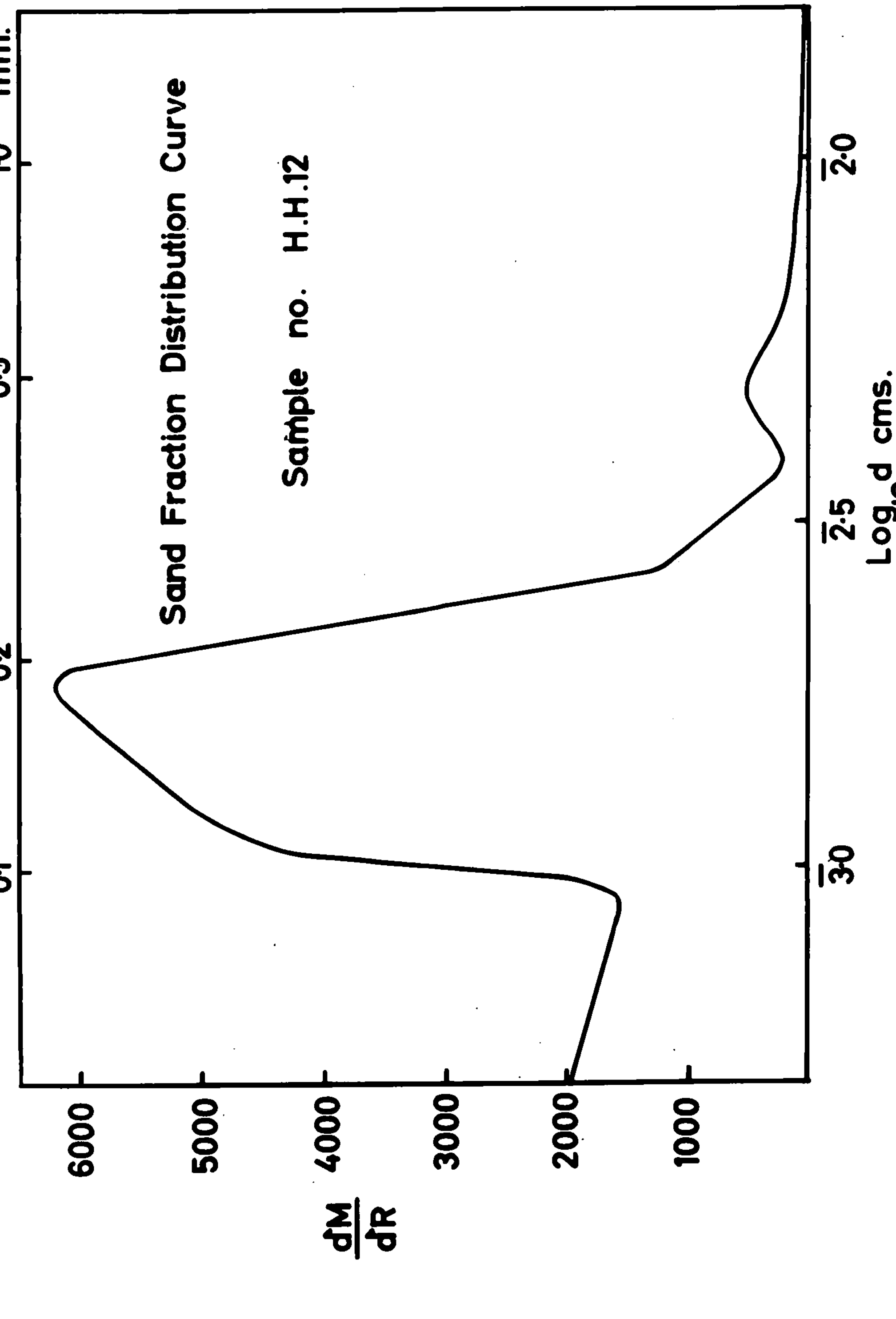

Sand Fraction Distribution Curve
Sample no. H.H.12
0·1
0·2
0·5
1·0
mm.
$\frac{dM}{dR}$
6000
5000
4000
3000
2000
1000
$\bar{3}$·0
$\bar{2}$·5
$\bar{2}$·0
$Log_{10}d$ cms.

FIG. 38

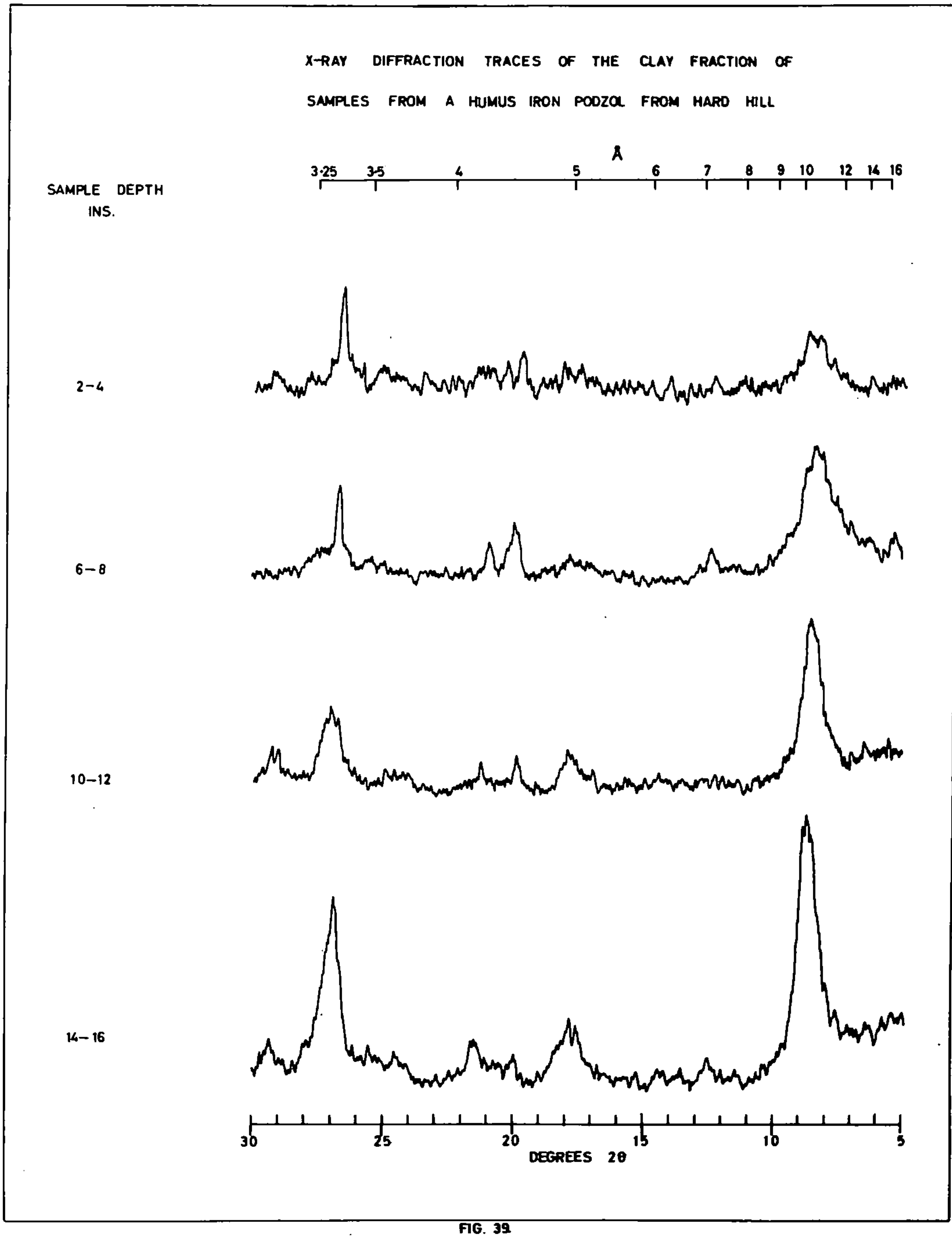

X-RAY DIFFRACTION TRACES OF THE CLAY FRACTION OF
SAMPLES FROM A HUMUS IRON PODZOL FROM HARD HILL
SAMPLE DEPTH
INS.
Å
3·25
3·5
4
5
6
7
8
9
10
12
14
16
2–4
6–8
10–12
14–16
30
25
20
15
10
5
DEGREES 2θ

FIG. 39

weathering profile. It is significant that muscovite is an important constituent of the Quarry Hazle sandstone.

Very similar results were obtained for the Great Dun Fell soil. Once again no foreign cobbles were found and all the fragments in the 2 mm. - 2 cm. size range were quartz or sandstone fragments plus a few iron and, or, manganese concretions. The sand content is somewhat lower than in the Hard Hill profiles but still high enough to necessitate derivation from a sandstone (Profile 16) or preferential accumulation of sand fraction material. The clay fraction is dominated by kaolin and once again the peaks increase in size and clarity with depth (Fig.40). The Dun Fell Sandstone contains kaolin, although the mudstones below the sandstone also contain kaolin.

In both cases the results indicate that the soil material was derived from the underlying sandstone and in situ. There may have been some addition of extraneous material, viz. the limestone fragment found by Park on Hard Hill, but this is insignificant in the genesis of these soils and when compared with the material derived in situ. Microscope examination of the material indicates a physical disintegration of the sandstone with little alteration, e.g. the muscovite in the Hard Hill profiles is very fresh looking. The next question is why a much deeper layer of disintegrated sandstone is found on Hard Hill and Cross Fell than on the other sites. The topography of the sites is almost certainly the answer with the large flat areas on Hard Hill and Cross Fell allowing accumulation of the disintegrated material but on the other, less extensive and less stable sites, the material was removed by solifluxion and hill wash. This also, almost certainly, explains the occurence of the two phases rather than differences in parent material as the different phases are found in similar parent material on Cross Fell and the Dun Fells.

16.3. The Origin of the Mountain Top Detritus.

The layer of disintegrated material on Hard Hill and Cross Fell indicate quite a long period of intense physical weathering such as would obtain in periglacial conditions. This period of periglacial

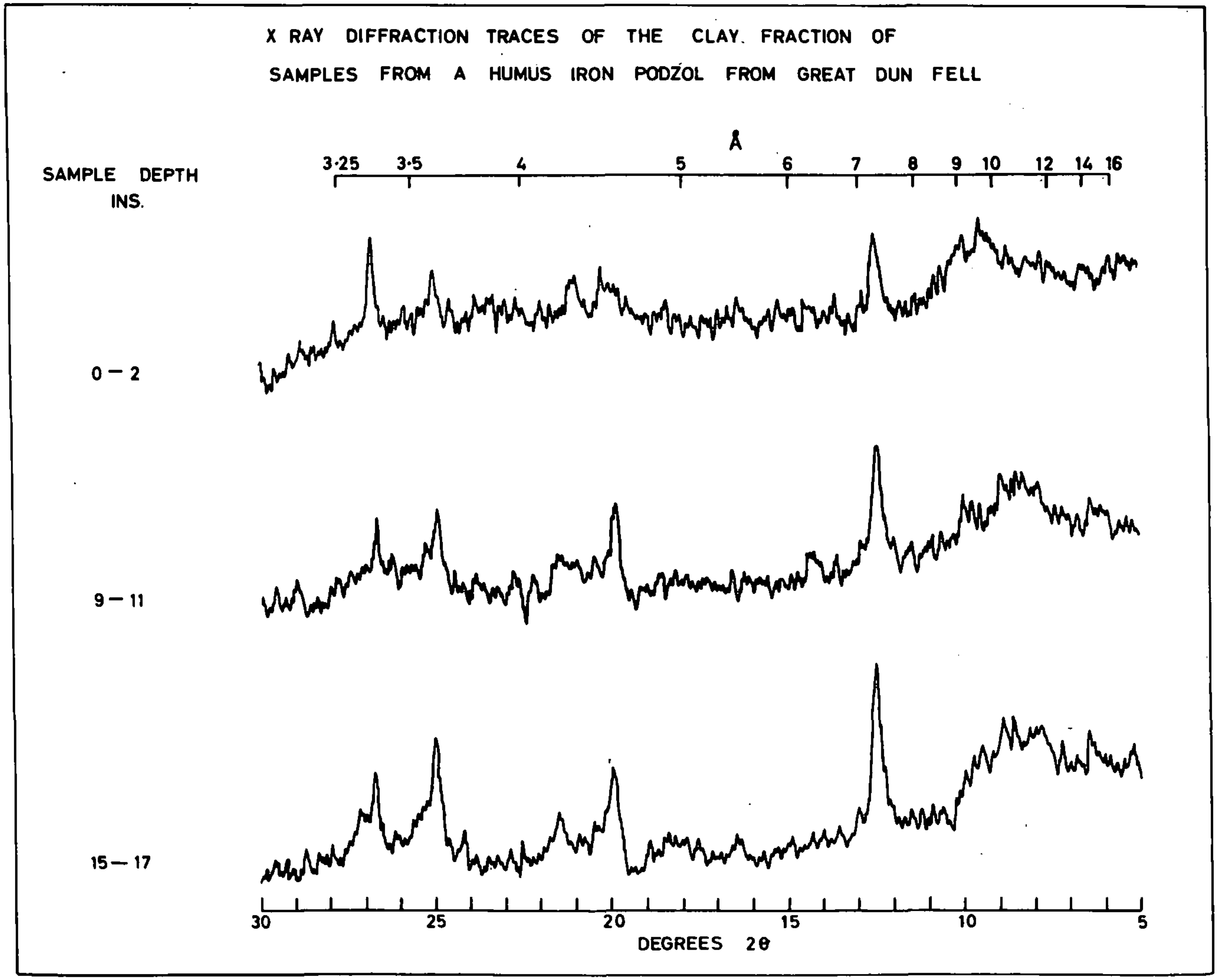

X RAY DIFFRACTION TRACES OF THE CLAY FRACTION OF
SAMPLES FROM A HUMUS IRON PODZOL FROM GREAT DUN FELL
Å
3·25
3·5
4
5
6
7
8
9
10
12
14
16
SAMPLE DEPTH
INS.
0 — 2
9 — 11
15 — 17
30
25
20
15
10
5
DEGREES 2θ

FIG. 40.

conditions may be the one which also produced the solifluxion phenomena, e.g. stone polygons and stripes and vertical blocks, or it may pre-date this period of solifluxion. The silty horizon with a platey structure is similar to that described from highland areas in Scotland by Romans et al (1966) and in those areas it is ascribed to freeze-thaw activity. The initial downward movement of fines taking place under sub-arctic conditions some time between 28,000 and 12,000 B.P. and the platy structure, which is due to flattened silt droplets, formed in conditions of rather less severe cold, i.e. the Allerod oscillation and the Boreal.

The layer of disintegrated material refered to above is worthy of further attention to see if more information on its mode of formation and age can be discovered. This type of material is refered to as mountain top detritus. Dahl (1955) uses the term to indicate "boulder fields in which the materials in situ have been weathered from the underlying rocks", or are "autochtonous" in character and he goes on to say that, "Almost all mountain top detritus of the British Isles belong to this class", i.e. the autochtonous class. He says that this usage of the term "is in accordance with the British usage" and quotes Tansley (1949 p.707). Tansley (ibid) in turn says the material is "so called 'mountain-top detritus' and has "accumulated in situ from the continuous action of frost and wind on the solid rock". It is interesting that one of the plates of the "mountain-top detritus" habitat which Tansley includes in his book is of Cross Fell, so that the Cross Fell material is "mountain-top detritus" by definition.

Romans et al (1966) refer to a recent symposium in Iceland (Love and Love 1963) in which, they say, "there seems to have been a measure of agreement that, in the northern hemisphere, this mountain-top detritus is probably pre-Wurm in age". It is true that Gjaerevoll and Ives both come to the conclusion that areas of mature mountain-top detritus which they studied were not covered during the last ice advances but many other authors, including others at the above symposium, sound a note of warning. At the symposium (Love and

Love, ibid), Hoppe states that, "The formation of mountain top detritus certainly is a complicated process with many variables, such as the properties of the bedrock, its condition before glacierization, the velocity and eroding capacity of the ice sheet in different situations, the conditions of deglaciation, postglacial climate etc." Discussion has been centred on these areas of mountain top detritus as they are considered by many to have been refuges for vegetation during the last ice advance. The greatest advocates of these ice free refugia are the botanists but geologists have been less ready to accept the areas as ice free during the last ice advances and hence to increase the age of the debris. Holtedahl's (1960) is typical of the geologists viewpoint and he states, "Concerning mechanically weathered rock masses at high altitudes or in peripheral areas the extremely different effect of weathering on the different rock types must be stressed", and he sums up as follows, "Felsenmeere (mountain top debris) is a common feature in many mountains or high plateaus which undoubtedly were overridden by the last inland ice." The point about rock types which Holtedahl makes is very pertinent to the areas being discussed at Moor House as they are composed of a medium to coarse grained sandstone which one can envisage breaking up rapidly under the influence of frost action. The existance of this type of mountain top detritus on rocks of this type cannot, in the present writers opinion, be taken in itself as 'carte blanche' for assuming the material to be pre-Wurm. Until the age can be proved the dates which Romans et al (ibid) put on the downward movement of fines and the formation of the platy structure must be used rather tentatively, although they will probably be proved to be correct.

Clay mineral studies of the type carried out by Dahl (1955) may well help to prove the age of the detritus and it is hoped to follow this up in the near future. Dahl has shown that in a number of localities the clay mineral formed from weathering of micas in the mountain top detritus are markedly different to those formed in surrounding areas which were definitely ice-cover during the last advance. The clays formed in the detritus would need a much longer period to form and different conditions.

If the areas of detritus prove to be pre-Wurm they will put an upper limit on any Wurm ice sheet at 2100 feet, the lower limit of the detritus on Hard Hill and Currick Hill, and make most of the summit ridge an ice free area above any ice sheet.

Humus Iron Podzol - Deep Phase

Profile no : 15 H.I.P. Sample no's : H.H. 1 to 5 and 11 to 13.

Location : Hard Ridge.

Nat. Grid. Reference : 726331.

Altitude : 2300 ft. O.D.

Relief and aspect : Bench on the E - W trending Hard Ridge, slight slope to the north.

Geological data : Bedrock is the Quarry Hazle Sandstone.

Vegetation : Festucetum.

Horizon :

ins	
L	Few recent leaves.
1.1/3 - 1½ F	Dark brown, plant remains recognisable, gradual, regular boundary.
1½ - 0 H	Black (2.5 YR 2/0), friable, peaty humus; a little mineral matter; moderate medium crumb; sharp regular boundary.
0 - 5 A_2	Grey brown (10YR 5/2), loose, very stony loamy sand; structureless - single grain to weak, fine crumb; abundant roots; low organic matter content; sharp regular boundary.
5 - 7 B_H	Black (5YR 2/1), friable, very stony loamy sand; weak medium crumb; frequent roots; low organic matter content; sharp regular junction.
7 - 12 B_2	Dark brown (7.5 YR 4/4), friable, stony sandy clay loam; moderate medium crumb; occasional live roots; low organic matter content; merging regular boundary.
12-18 B_3	Dark yellow brown (10YR 4/4), friable, stony sandy loam; weak medium crumb; occasional roots, low organic matter

content; merging regular boundary.

18 - 43+ C	Yellowish brown (10YR 5/6), compacted, stony sandy loam; structureless - single grain; no roots.

Profile no. 15 H.I.P.

Sample no.	Depth (ins)	p H	$CaCO_3$
H.H. 1	0 - 2	4.4	0
H.H. 2	2 - 5	3.9	0
H.H. 3	6 - 8	4.3	0
H.H. 4	10 - 14	4.5	0
H.H. 5	20 - 24	4.9	0

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
1	-	-	-	-	-
2	85.8	87.7	2.1	10.1	4.1
3	81.2	85.4	4.2	10.4	8.4
4	55.2	65.3	10.3	24.4	20.4
5	67.7	75.8	4.0	20.2	12.1

Extractable

	%B.S.	Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
1	5	0.49	0.3	0.11	0.07	33.84	15.1	1.06	14.2
2	8	0.31	0.12	0.10	0.03	1.52	0	0.046	-
3	9	0.46	0.18	0.18	0.05	4.60	1.6	0.091	-
4	12	0.52	0.17	0.13	0.03	3.19	1.0	0.032	-
5	16	0.51	0.19	0.14	0.07	2.58	0.7	0.036	-

meq./100g

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O	P %
1	n.d.	0.8	0.2	0.04	0.29	0.04	0.22	n.d.	0.007	n.d.	0.094
2	n.d.	2.0	1.7	0.03	0.23	0.02	0.49	n.d.	0.007	n.d.	0.018
3	n.d.	2.1	1.0	0.05	0.18	0.03	0.92	n.d.	0.002	n.d.	0.016
4	n.d.	5.6	4.1	0.15	0.28	0.20	2.43	n.d.	0.047	n.d.	0.036
5	n.d.	4.1	3.6	0.09	0.15	0.10	1.72	n.d.	0.009	n.d.	0.016

<u>Humus Iron Podzol - Shallow Phase.</u>

Profile number : 16 H.I.P. Sample numbers : W.29 - 33.

Location : Northern end of the summit area of Great Dun Fell.

Nat. Grid Reference : 323710.

Altitude : 2775ft. O.D.

Relief and aspect : The summit area is virtually flat but drops away steeply from the edges of this area.

Geological data : The Dun Fell Sandstone is bedrock.

Vegetation : <u>Festucetum</u>.

Horizon. ins.	
L	- Trace, mainly grass leaves.
F	Brown, plant remains recognisable.
1¾" - 1½"	
H	
1½" - 0	Black, friable, smooth, mor humus; sharp regular boundary.
0 - 2	
A_2	Grey black (10YR 3/1), loose, very stony, sand; structureless to very weak fine crumb; frequent roots; general appearance is of a mixture of bleached quartz
2 - 4¼	grains and raw humus; gradual, regular boundary.
B_{1H}	Black (5YR 2/1), very stony, friable, sandy loam; moderate medium crumb; frequent live roots; fairly sharp regular boundary.

$4\frac{1}{2}$ - $7\frac{1}{2}$ B_2	Brown (5YR 2/2), stony, friable sandy loam; moderate fine to medium crumb; roots; merging boundary.
$7\frac{1}{2}$ - $11\frac{1}{2}$ B_3	Light brown (10YR 4/2), friable, stony, sandy loam; weak medium crumb; occassional roots; merging boundary.
$11\frac{1}{2}$- 16 C	Light brown (10YR 4/2), very stony, friable, sandy loam; structureless; roots to 14"; really sandstone blocks with sandy loam between. First complete bedding plane at 16".

Profile no. 16 H.I.P.

Sample no	Depth (ins)	p H	$CaCo_3$ %
W.29	0 - 2	4.1	0
W.30	3 - 5	4.2	0
W.31	6 - 8	4.6	0
W.32	9 - 11	4.9	0
W.33	15 - 17	4.9	0

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
29	55.0	69.2	11.9	18.9	26.1
30	52.6	66.2	15.8	18.0	29.4
31	43.5	52.2	17.4	30.4	26.1
32	34.6	51.5	19.0	29.5	35.9
33	47.3	67.1	11.8	21.1	31.6

		Extractable							
	% B.S.	Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
29	10	0.78	0.49	0.75	0.30	15.33	5.43	0.71	7.8
30	4	0.48	0.17	0.70	0.1	11.06	3.39	0.03	116
31	6	0.38	0.13	0.44	0.1	9.93	2.86	0.086	-
32	15	0.39	0.85	0.37	0.14	7.24	1.58	0.071	-
33	16	0.35	0.04	0.35	0.15	6.72	1.33	0.08	-
		meq./100g							

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O %
29	77.39	6.77	1.45	0.04	0.53	0.74	0.80	0.55	0.03	6.36
30	77.31	8.67	2.77	0.09	0.52	0.72	0.83	0.61	0.04	5.06
31	57.47	19.92	8.30	0.59	0.46	0.62	1.41	1.13	0.07	7.12
32	56.15	24.87	5.65	0.98	0.44	0.59	1.72	1.15	0.09	6.89
33	62.01	15.12	4.96	1.44	0.49	0.72	2.21	1.48	0.06	10.14

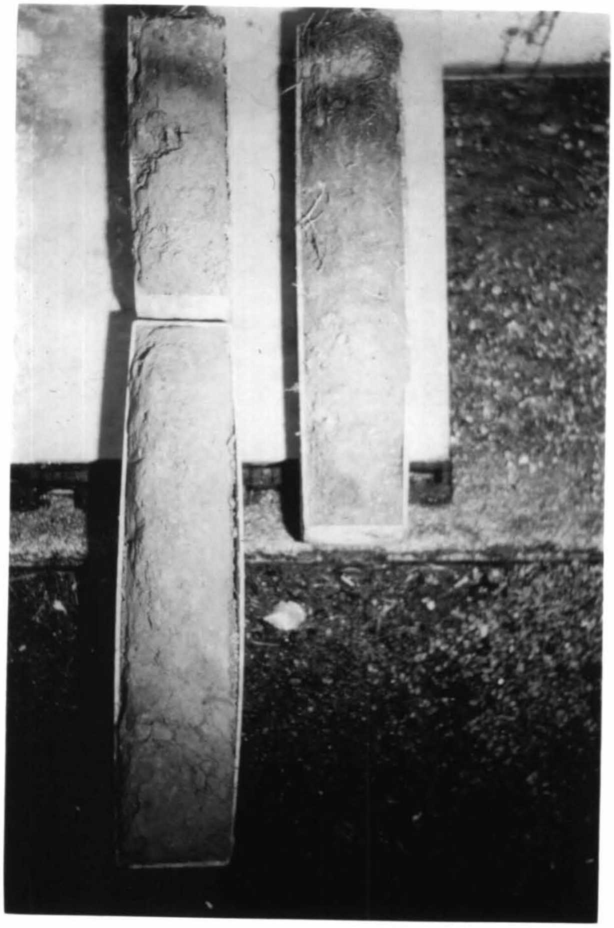


Plate 54. Humus iron podzol monolith from Cross Fell.

Plate 55. Humus iron podzol, Little Dun Fell.

CHAPTER 17

Peaty Gleyed Podzols

17.1. Introduction

The peaty gleyed podzols are similar to those described briefly in connection with the limestone grassland sites. They are found at all levels on the western escarpment and on the eastern slopes of the Reserve. The parent material consists of a layer of superficial material, of varying depth, stoniness and composition, overlying various rocks of the Carboniferous succession. The vegetation associated with this soil sub-group is either a *Nardetum sub-alpinum* (p.59) or a *Juncetum squarossi sub-alpinum*, with the *Nardetum* being rather commoner.

17.2. Relatively Constant Features of the Morphology.

Within the peaty gleyed podzols a fairly large amount of variation is found. These variations could provide a means of sub dividing the peaty gleyed podzols, e.g. peaty gleyed podzols, peaty gleyed podzols with thin iron pan, peaty gleyed podzols with manganese cementation, but the various types have been grouped together here as the variation is often rapid and each persists over only small areas. Certain features of the morphology remain reasonably constant throughout the sub-group and these will be dealt with first.

A surface layer of acid, mor, humus is always present and this usually thickens in one direction until blanket peat is found. The division between blanket peat and peaty gleyed podzol is, in this case, purely arbitrary and there are grounds for discussing a sub-peat peaty gleyed podzol. The junction between this peaty humus horizon and the underlying soil is always sharp although it may be somewhat irregular. The humus itself is always black and usually greasy; it is, also, always wet and generally saturated.

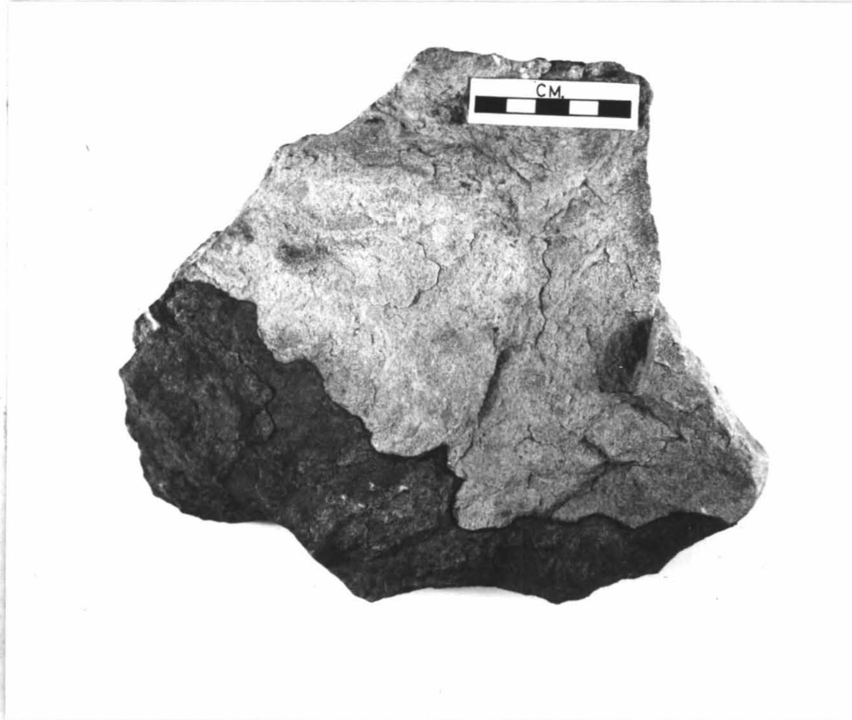


Plate 56. A_2 - B boundary on a sandstone boulder.

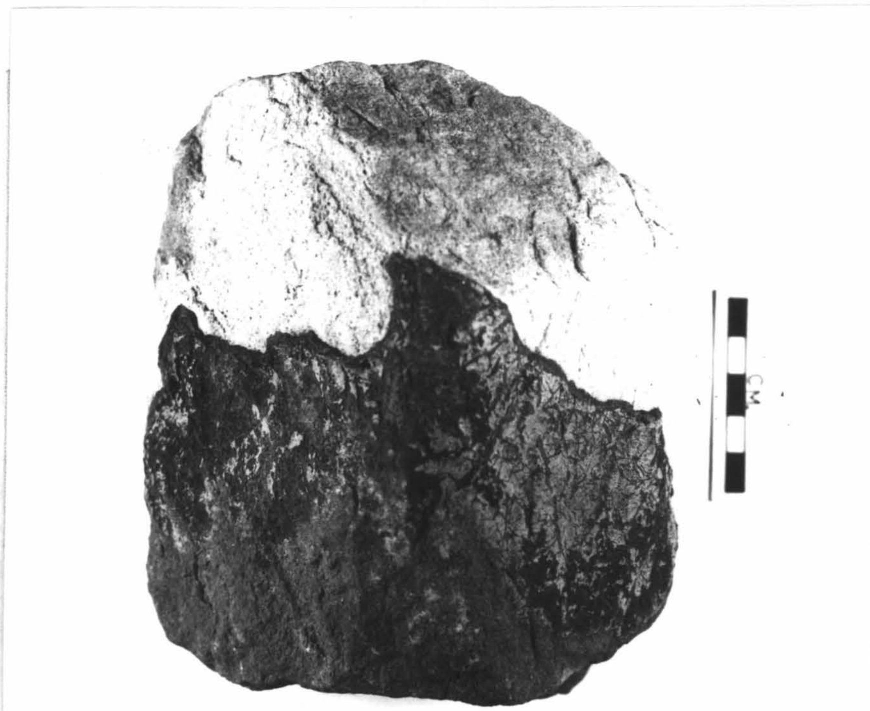


Plate 57. A_2 - B boundary on a sandstone boulder. Root marks can be seen on the boulder in the B - horizon.

An A_2 horizon always underlies the humus, H, horizon. This horizon is always gleyed to some extent and contains abundant live roots: it is usually damp. The colour of the A_2 is usually a grey or grey brown. The structure is always weak but varies in type. The base of the A_2 is very sharp but may also be very irregular. A sharp colour change is present at the A_2 - B interface, the B being a brown or reddish brown. This colour change would seem to reflect, in part, the fact that the A_2 is always depleted of iron and the B enriched in iron (Profiles 17 to 20). The colour change also reflects the fact that the sub-soil is apparently always better drained than the A_2 ; but not always freely drained.

Boulders in the soil at the A_2 - B junction often show the boundary very clearly; the part of the boulder in the A_2 being bleached white whereas the part in the B is stained brown (Plates 56-60). The junction of the horizons on the surface of the boulder is at the same position as in the surrounding soil. The boundary is also reflected within the boulder but its position there depends on the porosity of the boulder. In sandstone boulders the junction is usually lower within the boulder than on its surface (Plate 58). In the case of fine grained Whin Sill there is no evidence of the boundary within the boulder; the Whin Sill being very impervious. In granitic boulders the part of the boulder within the A_2 may be rotted (Plate 59): the same is true of the pegmatitic Whin Sill (Plate 60).

The horizon differentiation is much less obvious in the sub-soil and can be very difficult. The colour changes are less marked and take place gradually. They are usually from a strong or reddish brown to a yellow brown or brown yellow. The B_2 and C horizons are often highly compacted with a weak structure, but induration is rare.

All the profiles examined were stony to very stony throughout. The texture was variable, from a sandy loam to a clay loam,

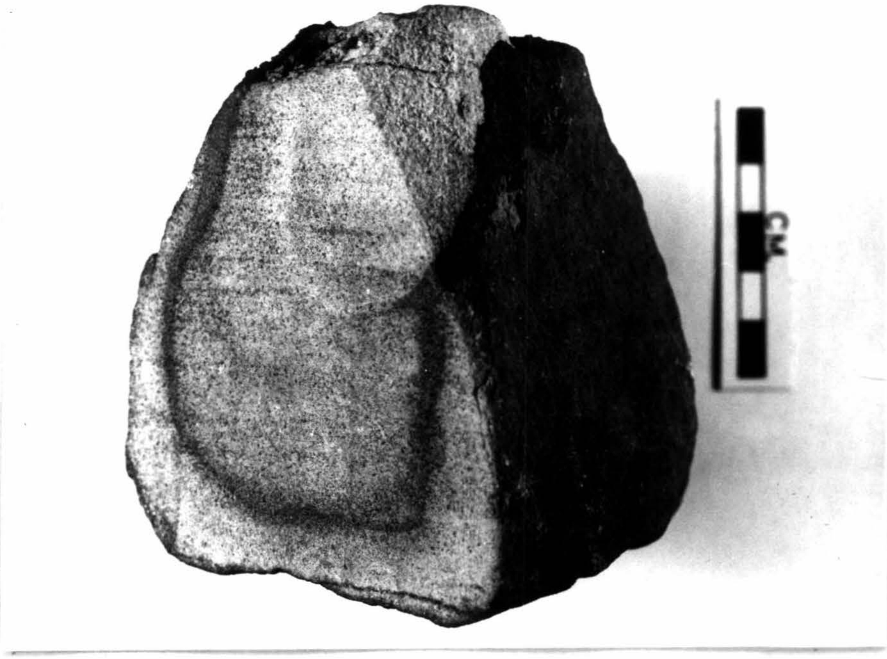
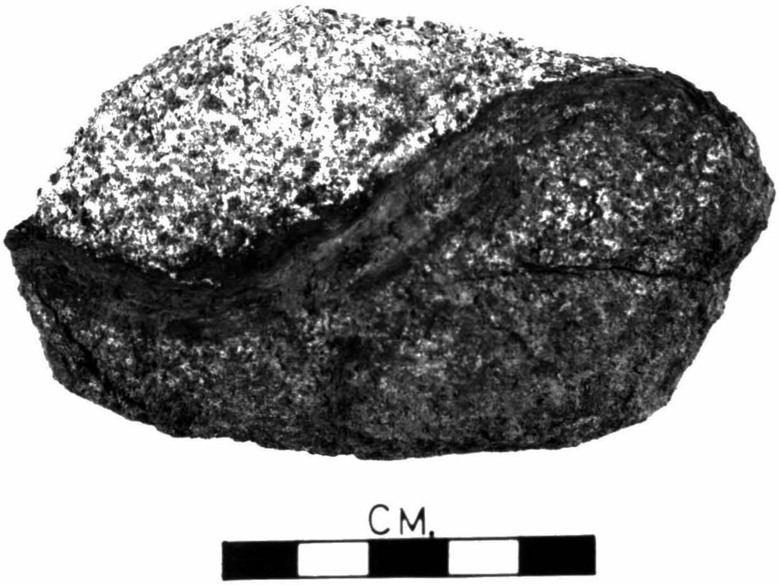


Plate 58. A_2 - B boundary within a sandstone boulder.

Plate 59. A_2 - B boundary within a granitic boulder.



<u>Plate 60.</u> A_2 - B boundary on a pegmatitic Whin Sill boulder. The part of the boulder in the A_2 is more heavily altered.

but no pattern of variation was detected within profiles. Textural variation within the profile was sometimes present but the variation was not present in all profiles. The presence of clay skins along any vertical cracks in the soil and also along root channels indicate that clay movement is now taking place. All the soils were extremely heavily leached and the percentage base saturation of the mineral soil was usually below 10 and commonly below 5. The pH values reflect the general acidity and were usually between 4 and 5 with a slight increase down the profile.

17.3. Variations in the A_2 Horizon.

The variations within this general morphology will now be examined. The A_2 horizon varies somewhat in colour and also in thickness. The variation in colour is from a blue-grey to a dull yellow brown. The greys and blues are found in profiles where the A_2 is underlain by a thin, but impermeable, iron pan which may well produce a perched water table. The grey-browns and yellow browns are usually found in profiles which do not have an iron pan : in iron rich parent materials the yellows and browns seem more likely to persist e.g. Profile 18 . The depth of the A_2 would appear to depend on the presence or absence of an iron pan, the depth of peaty humus at the surface and the texture. If an iron pan is present at the upper boundary of the B horizon the whole of the overlying mineral soil will usually be gleyed. The depth of the gleyed A_2 tends to increase somewhat as the thickness of the surface peat increases but above about 18 ins. of peat further increases do not seem to be reflected in any further increase in the A_2. The effect must be related to the depth of soil material that can be maintained in a damp condition by a given thickness of peat. The thickness of the A_2 is greater on heavier parent materials than on light.

Plate 61. Peaty gleyed podzol, Moss Burn - Sheep Fold Site.

Plate 62. Peaty podzol developed in head derived from the Whin Sill.

17.4. Iron Pans.

A thin iron pan may be present in the B horizon (Plates 63-65). The pan may be at the A_2 - B interface, the B-C interface, or within the B horizon (Profile 17). It is most commonly at the A_2 - B interface (Profiles 18-20). The typical pan is very thin, up to ¼ inch, but it varies considerably in hardness. A dense root mat is usually present on the upper surface of the pan and this is most marked when the pan is at the A_2 - B interface. The pan is typically very sinuous and when the pan is at the A_2 - B interface this boundary is very irregular (Plate 66). It is notable that when the iron pan is absent from the profile or not at the A_2 - B boundary this boundary is far more regular. Also when a pan is present at this upper boundary the B_2 is much more difficult to distinguish from the B_3. In the absence of a pan the upper B horizon, B_2 , is a much stronger brown than the B_3 (Plate 61) but when a pan is present the difference is much less marked. This is almost certainly because when a pan is present most of iron illuviated from the A_2 is locked up within the pan whereas when the pan is absent the iron is diffused through the top two or three inches of the B horizon.

The typical pan has a fairly constant morphology. The upper surface is a black or dark brown colour. The colour is probably due to humic material but it is difficult to determine whether it has been carried down from the overlying humus layer or derived in situ from the root mat usually present. In the 'fossil' peaty gleyed podzols below blanket peat many of the roots on the upper surface of the pan have been replaced by iron rich material which has a resinous texture. Below the dark coloured layer a dull red is generally found and below this a yellow to orange-yellow layer. When examined in polished and thin sections the whole of the pan is seen to be a skeleton of rock fragments and mineral grains cemented by a dark red, iron rich amorphous looking plasma which fills the spaces between the mineral skeleton. Coninick and Laruelle (1964) refer to what appears to be similar material as "a non-birefringent plasma, consisting primarily

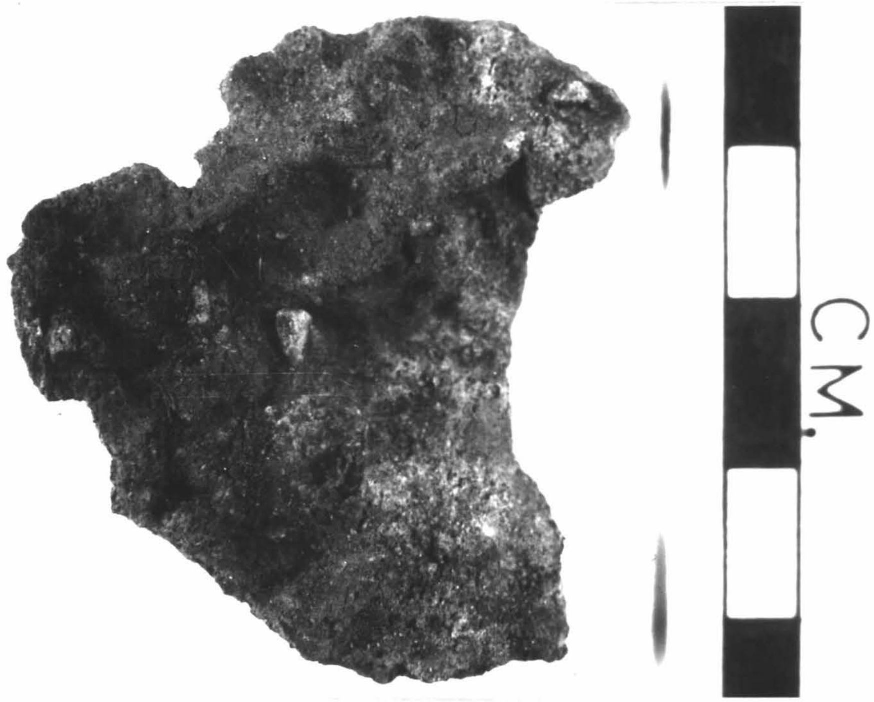


Plate 63. Upper surface of a fragment of thin iron pan.
Small pebbles are embedded in the pan.

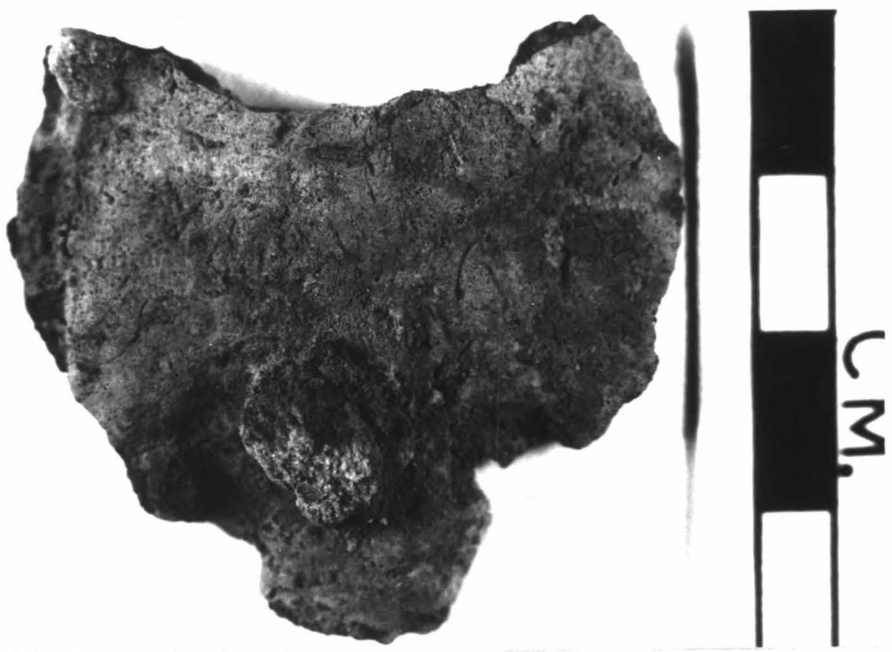


Plate 64. Lower surface of the fragment of iron pan.

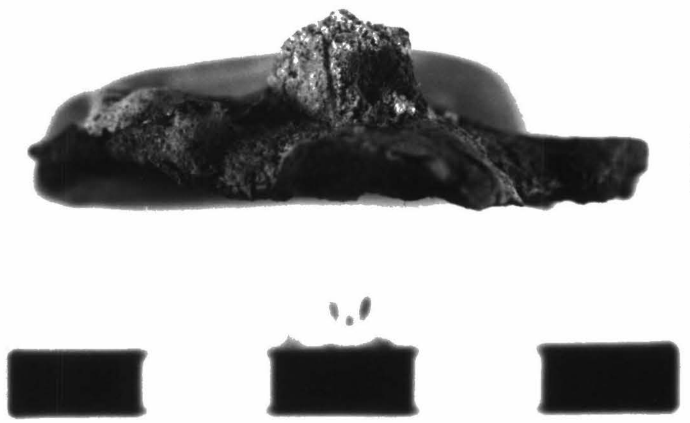


Plate 65. A fragment of thin iron pan : end view.

of free oxides and of organic matter". As the mineral composition of the soil is always dominated by quartz this always dominates the skeleton of the pan. That fraction of the iron of the pan which produced an X-ray pattern was mainly present as goethite although a little lepidocrocite was almost always present. Crompton (1956) found goethite was the main constituent of iron pans he examined from a Lancashire soil.

The iron pan varies greatly in hardness and brittleness. In some cases it is soft and crumbly whereas in others it is firm and brittle. The soft crumbly pans are usually yellow and differ from the typical pan in not having a dark upper surface and not being stratified. It is significant that no clear X-ray pattern, other than quartz, could be obtained from these pans. The hardest pan material is usually found in fossil soils below deep blanket peat and the hardening may be due to aging of iron oxide gels. In some pans one finds black resinous areas which give a shiny black surface on breaking them open, e.g. on Knock Fell (Profile 17). This material would appear to be similar to that described by McKeague et al (1966) from Newfoundland : they describe the pan in Newfoundland as, " hard, cemented, black, vitreous material a few millimetres thick". The Newfoundland pan was identified as iron-humic complexes and chiefly fulvic acid-iron complex : McKeague et al (ibid) refer to these pans as iron-humus pans. The black shiny material may well indicate that these pans have a much higher humus content than the typical iron pan found at Moor House and this compositional difference may well be indicated by the fulvic acid-iron complexes identified by McKeague et al (ibid).

17.5. Manganese Cementation.

Another type of cementation of soil material has been found associated with peaty gleyed podzols at one locality. This

Plate 66. Peaty gleyed podzol on the slopes of Knock Ore Gill.

cementation is at or near the base of the B horizon and is a much thicker zone than the 2 or 3 millimetres of the thin iron pan just discussed. In this case up to 9" of the soil material was cemented with iron and manganese (Plate 67). The cemented part of the soil was extremely hard and had to be broken with a hammer : it would be impermeable to downward moving water. The margins of the cemented area are not sharp as with the thin iron pan and the upper boundary is difficult to distinguish from overlying horizons visually. This type of cementation is similar to what is understood by iron pan in soils other than the thin iron pan soil and is similar to the ortstein of other podzol types. McKeague (1967) has described similar cementation from below blanket peat in Newfoundland and has refered to it as iron-manganese pans. The upper part of the cemented layer has a strong brown colour and a layer of iron rich material coats the soil skeleton and cements it together. The lower part of the pan was a black colour and the underside of it had a cindery appearance and was almost always damp. The manganese acts as a cementing agent. The boundary between the upper, iron rich, part of the cemented zone and the lower, manganese rich, part is suprisingly sharp and must represent a delicate chemical separation of the two elements. The manganese cements the soil material more firmly than does the iron and the extreme hardness of the pan seems to be due to the manganese. This type of cementation was restricted to extremely gravelly material and was often at, or near, the interface between an extremely stony layer and an underlying less stony layer. The profiles with this type of cementation are also associated with streams and two profiles were excavated in stream sides and the manganese cementation is near the water table. The author has found similar cementation in gravel beds several feet below the surface on the banks of the Tees and in this location the material must have been below the water table or very close to it.

Manganese accumulation is also found in some peaty gleyed podzols found around swallow on Knock Fell. In this case a layer of

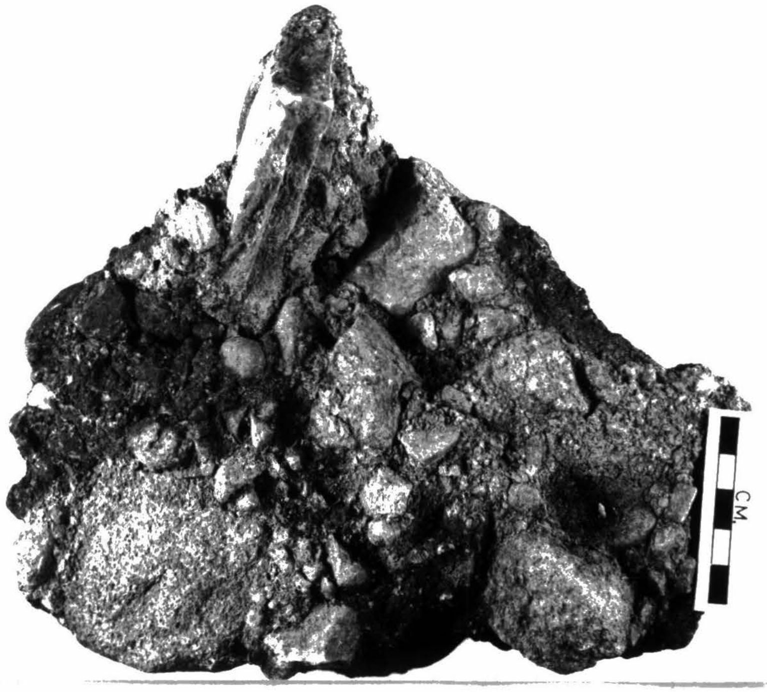


Plate 67. Manganese and iron cementation in a gravelly parent material : the areas of manganese show as darker areas.

iron and manganese concretions is found very close to the superficial material - limestone interface. In this case the accumulation is not associated with a very stony parent material but with a loam. There is no textural interface at the point where the layer of concretions is found and with which the accumulation could be connected.

Although this marked manganese accumulation, i.e. sufficient to produce a pan, is absent in the normal peaty gleyed podzols manganese staining or concretions are quite frequently present at the base of the B horizon. The staining is always on pebbles or larger stones and is the black colour often associated with manganese. The concretions are generally between 1 and 2 m.m. and sometimes they contain quartz grains but frequently they are pure manganese material which must have formed in small cavities in the soil. When the concretions are broken open they often give a very shiny fracture surface.

17.6. Variations in Sub-soil Drainage.

The B horizon is freely drained when compared to the A_2 but it is not always entirely freely drained. The grey colours which predominate in the A_2 are evidence of the impeded drainage and the B and C horizons usually lack these colours but examples have been found with impeded drainage of the B and C horizons (Profile 19). The drainage was never found to be impeded enough to produce waterlogging and a uniform grey colour but mottling of the B horizon was found at several sites (Profile 19). The mottles were ochreous and usually on a grey brown background. The mottles were present throughout the subsoil and in extreme cases the ground colour of the subsoil became a blue-grey with increasing depth, indicating almost complete waterlogging. In the soils with impeded drainage in the subsoil the zone of iron accumulation in the B, is often very distinct and a deep red-brown colour. The only examples with a very distinct zone of iron accumulation below an iron pan at the A_2 - B boundary were those with impeded drainage at depth.

Plate 68. Peaty gleyed podzol on the slopes of Knock Ore Gill. The mottling below the pan can be clearly seen. Profile 19 P.G.P.

17.7. Variations in Structure.

The structure of the soils is generally weak. The subsoil is generally structureless or has a weak to medium blocky structure. The A_2 horizon may have a weak prismatic structure but this is the exception rather than the rule. The subsoil often has a high bulk density and the iron pan acts as a barrier to roots which would help in creation of structural units. The higher level peaty gleyed podzols, e.g. on the bench to the south of the summit of Great Dun Fell and on Knock Fell, have a marked platy structure in the B horizon. The origin of this platy structure is probably the same as in the case of the humus iron podzols (p.328). An increase in fines within the B horizon is also present in this high level type (Profile 17). The presence of the platy structure and the increase in fines in these peaty gleyed podzols indicates that the processes giving rise to them were not restricted to the humus iron podzols. The controlling factor would seem to be altitude as these features are only found in the higher level soils.

17.8. Examination of Hypotheses of Peaty Podzol Formation.

The peaty surface humus layer and the grey coloured A_2 horizon are constant features of the profile. The peaty layer is saturated with water throughout the year and undoubtably maintains the upper part of the soil profile, i.e. the A_2 horizon, in a wet condition throughout most, if not all, of the year. The depth of mineral soil which is maintained in this saturated condition will depend on the thickness of the layer of peaty humus, the texture of the soil material and the presence or absence of changes in soil texture with depth, e.g. a change to a more impermeable layer will impede drainage, as the thin iron pan does (p.353). In the waterlogged conditions obtaining in the A_2 horizon iron may be reduced to the ferrous state and mobilised. The

Plate 69. Discontinuous iron pan at the interface of solifluction deposit and insitu weathered shale. (Scale is 6 ins);

reduction and the mobilisation may or may not be connected and the grey colours of the A_2 could be produced by reduction alone. That mobilisation and subsequent deposition of iron does take place is evidenced by the accumulation of iron in the B horizon, either as a thin iron pan or as a rather thicker zone of iron enrichment. The B horizon is apparently freer drained and oxidising conditions may obtain there.

This sequence of iron reduction in the waterlogged A_2, followed by mobilisation, and then re-oxidation and deposition in the freely drained B horizon is the one suggested by Muir (1934) to explain the genesis of the peaty gleyed podzol. Crompton (1956) and Crampton (1963) have also used this hypotheses but with modifications; Damman (1965), after reviewing some of the work on peaty gleyed podzols, also accepts the sequence.

Many people have investigated the mobilisation of iron in experimental systems. Bloomfield (1951) has produced reduction of iron by extracts from plant debris in an anaerobic, slightly acid environment, and in anaerobic environment in neutral conditions (Bloomfield 1953, 1954b) and alkaline conditions (Bloomfield 1954a). Muir et al (1964) have produced mobilisation of iron as organic-iron complexes using aqueous extracts of pine needles. These are all non-biological processes but microbial reduction of iron has been obtained in anaerobic and markedly acid environments, e.g. Bloomfield (1950), Bromfield (1954) and Betremieux (1954). Bromfield (1954) also showed that the bacteria capable of reducing ferric iron were present in the surface layers of gleyed soils. These mechanisms provide a means for reduction and mobilisation of the iron in the A_2 but as Crampton (1963) remarks, "... the microbial, anaerobic reduction would appear responsible for the experimental mobilisation of iron at the low pH values characteristic of iron pan podzols." The subsequent reoxydation and immobilisation of the iron seems rather more difficult to explain; Deb (1949) suggests a microbiological mechanism. Work by

McKeague et al (1967) indicates that a polymerisation of the organic-iron complexes takes place producing insoluble polymers: the cause of the polymerisation is uncertain. The reoxidation and immobilisation takes place in the relatively better aerated part of the subsoil whatever the precise mechanism involved and this better aeration would seem to be a controling factor.

Evidence from Moor House shows that an entirely freely drained subsoil is not essential for formation of a peaty gleyed podzol, with or without an iron pan.

Peaty gleyed podzols with a gleyed subsoil are quite common (Plate 68, Profile 19). The mottles in these gleyed subsoils may indicate a seasonal waterlogging or they may be associated with rather more aerobic conditions around root channels. The ground colour of these gleyed subsoils was generally a yellow brown or grey brown and not the dull greys or blue greys of the true gleys so that the mottles may well indicate mobilisation of iron in seasonal waterlogging. It seems that a peaty gleyed podzol can form so long as the subsoil is free of standing water for at least part of the year, so that in that part of the year oxidising conditions exist below the reducing A_2. In this type of soil it will be essential for more iron to be removed from the A_2 and immobilised in the upper part of the B when the water table is high.

It seems that ferric iron is reduced and mobilised within the saturated zone below the peaty surface material. Damman (1965) says of the upper part of the mineral soil below blanket bog, "the zone with capilliary water hanging under these bogs will keep the upper part of the mineral soil saturated with water", and this seems to give an accurate picture of the conditions prevailing in the A_2. The reduced iron, now in a ferrous state, may be transported down the profile as organic complexes formed with products of the decay of plant materials. When these complexes reach the relatively freer drained subsoil the iron is reoxidised to the ferric state and immobilised thus producing an iron enriched layer.

An abstract of work by Kaurichev (1967) is pertinent at this point. "When podzol formation is accompanied by seasonal surface-waterlogging, formation of the eluvial horizon is the result of the simultaneous occurrence of both podzolisation and the eluvial gley processes. Seasonal surface gleying stimulates podzolisation by transforming mineral components of the soil into more soluble forms and by promoting the formation of acidic organic compounds".

The formation of the thin iron pan, the iron-manganese pans, the manganese pan and the manganese concretions are obviously related to the processes above but it is difficult to explain some aspects of these features. Muir (1934) suggests that the iron pan forms at the upper surface of the B_2 horizon of a normal podzol, the B_2 having become impermeable due to hardpan formation; Stephens (1950) supports this theory. This is envisaging the pan forming at a textural, or structural discontinuity within the soil, in this case the $A_2 - B_2$ or $B_1 - B_2$ interface. Atkinson (1962) also found that the thin iron pan in three podzols he examined had formed at an interface, in this case the upper surface of the indurated horizon commonly found in Scottish soils. The tendency for pan formation at an interface is found in some soils at Moor House.

On Knock Ridge (Plate 69) 'drift' material is found overlying a layer of disintegrated shale which in turn overlies in situ, little disturbed, shale and in this case a thin iron pan has been formed at the upper surface of the undisturbed shale. The thick iron-manganese pan discussed earlier (p.356) is at the interface of a stony horizon with a much less stony one, in this case at the base of the B horizon. From these examples it would seem that if an interface is present in the soil pan formation is likely to take place at that interface.

The profiles mentioned above are atypical when one considers the vast bulk of the peaty gleyed podzols found at Moor House. In the typical peaty gleyed podzol with thin iron pan the iron pan is at the A_2 - B junction and no marked structural or textural change is found at this junction. The pans which are at an interface were rarely in the typical position and usually lower in the profile. Another difference in the pans was their form in the soil : those found at interfaces were usually at a constant level within the soil whereas the more typical pans had a very sinuous course.

Crompton (1956) considered the pan forming in the aerated B horizon below the anaerobic A_2 but does not consider its position in detail. Muir (1934) also considered this a possible position for the pan. Damman (1965) supports these theories and says that the pan will be at the air-water interface at the base of the saturated zone. Crampton (1963) has the following to say, "The better aerated environment at the surface of the B_S horizon would allow precipitation to initiate the iron pan". This kind of explanation would seem to fit the pan as found in the typical profile at Moor House. The sinuous nature of the pan is considered by Damman (ibid) to be due to the varying depths of the saturated zone and Muir (ibid) says that it could be due to, "slight textural variations in the boulder till". These factors could be closely related. Crompton (1956) suggests that some of the variations in depth may be due to a gradual migration of the pan down the profile ; Damman (ibid) also admits this as a possibility. It is difficult to imagine these factors causing the large, rapid variations in depth which are found but it has not been possible during the present work to discover any alternative causes.

McKeague et al (1967) comment that the hypothesis of reduction and mobilisation in the saturated part of the profile and oxidation in the aerated lower part, as advanced by Damman (1965) and

Crompton (1956), "does not appear to be adequate for several reasons". They continue that if the theory were correct then the composition of the pan would be iron oxide whereas the pans they examined were iron-fulvic acid complexes. At least part of the pans examined at Moor House was present as goethite and lepidocrocite and, as mentioned earlier (p.353), the pans Crompton (1956) examined in Lancashire were mainly goethite. In this case, then, some of the iron was present as oxides, but without further work it is impossible to say that most of the iron is not present as iron-fulvic acid complexes as in the Newfoundland pans. The further criticisms of McKeague et al (ibid) are that on Damman's hypothesis the pan should be found at the boundary between fine and coarse material and that "previous work(McKeague 1965) showed that reducing conditions did not occur above the water table in the soils studied and that oxidising conditions (high Eh) did not persist in the lower horizons when the Eh values of the surface horizons were low". On the first point one can see no reason why the pan must be at the textural junction although it is likely to pick it out. The depth of the "zone with capilliary water hanging under" the "sponge horizon" (Damman, ibid) will depend on several factors such as effective head of water due to the "sponge horizon", texture of soil material and presence, or absence, of textural interfaces. Under a sufficient head one can envisage the saturated zone reaching below a textural interface. The difficulty is encountered when pans within the B horizon are considered, as opposed to those at the upper surface of the B horizon. If these pans within the B horizon are at a textural interface then this may have determined their position but if no such interface is present it is difficult to see why, applying Damman (ibid) and Crompton's (ibid) hypothesis, the pan should be anywhere but the upper surface of the B horizon. To this extent the present writer agrees with the criticism of McKeague et al (1967).

The question of reducing conditions above a water table and oxidising conditions at depth are difficult to imagine and McKeague et al (ibid) further point out that, "It is difficult to conceive of circumstances permitting aeration well below the surface if the surface horizons of soils are under anaerobic conditions." The work which McKeague (1965) carried out on the Eh values existing in various soils is the type of approach which will help to show whether or not reduction and mobilisation followed by oxidation and immobilisation is a possible explanation. Despite this it is doubtful whether the results obtained by McKeague can be applied directly to peaty gleyed podzols. If they can then one has to agree with McKeague et al (1967) that Damman's hypothesis is dubious because it hinges on the fact that reducing conditions can be underlain by oxidising conditions. It should be pointed out that most of the difficulties regarding the existance of reducing and oxidising conditions in the various horizons may be overcome if the reduction and oxidation are carried out entirely by bacterial action.

Another approach which would be rewarding is an investigation of the hydrological problems involved. The hypothesis outlined above seems to imply a layer of water below the peat, Damman's (1965) "zone of capilliary water" with a water free layer below this and below this another layer of water, i.e. below the permanent water table. From a hydrological point of view this would seem to be impossible. The situation could exist if the upper saturated layer were a perched water table and this could be realised in a profile with a textural change from pervious to impervious or a profile with an iron pan. This would necessitate the iron pan predating the gleying of the A_2 horizon. Without the perched water table it is difficult to see how the two saturated zones can exist without being connected. The only situation which one can envisage is one with extremely slow movement of water in the zone below the peat which maintains anaerobic, oxygen poor conditions. Below this zone the water movement may be rather more rapid and may allow a relatively oxygen rich environment to exist. This system would necessitate having oxydising conditions below a water table, a condition which McKeague (1965) says did not exist in any of the soils whose Eh conditions he studied. At Moor House the association of the peaty gleyed podzols with moderate slopes (p.450) may indicate that a lateral component in the water movement is of importance here. If one contrasts these soils with the peaty gleys it may well be in the peaty gleys one has stagnant water conditions while in the peaty gleyed podzols water movement is taking place.

The pans in the typical peaty gleyed podzol profiles at Moor House are at the junction between the gleyed horizon and the freer drained subsoil. In the examples with obviously impeded drainage of the subsoil the pan is at the junction of the gleyed, uniform, A_2 with the mottled B horizon so that although the subsoil is not entirely freely drained the pan is still at a boundary below which the drainage seems to improve. In these cases the water content and drainage characteristics of the soil would seem to be the important factors in pan formation, rather than the presence of textural or structural interface.

In his conclusions Damman (ibid) comments that "In spite of the poor drainage vertical percolation of water must be able to take place so that iron can be leached to the area of pan formation. This is the reason for their absence in fine textured soils and soils with a genuine ground water level". He then adds, "Normally these conditions are fulfilled only on sandy or gravelly soils in perhumid climates but locally they may exist elsewhere". At Moor House all the peaty gleyed podzols with thin iron pan are developed in material with a considerable content of fine material, usually 20 to 30% clay and silt. When a profile pit of a peaty gleyed podzol with a freely drained subsoil was repeatedly filled with water this had almost all drained away by the following morning and indicates that, despite the high content of fines, drainage of the subsoil is relatively free. This degree of drainage is not always present at Moor House and, as will be shown later, some factor must be introduced to improve the drainage before peaty gleyed podzols will form. This once again shows that drainage of the subsoil is the important factor in formation of the peaty gleyed podzols. This being so one has to stress that the hypothesis put forward by Damman (1965), Crompton (1956) and Muir (1934) does not satisfy all the requirements of the formation. The serious criticisms of McKeague et al (1967) have been mentioned and the hydrological difficulties pointed out. Without knowing the Eh conditions and the hydrology of these soils it will be impossible to come to rigid conclusions about their formation and so it is in this direction that further work should take place.

The movement and accumulation of manganese must be controlled by similar factors to those controlling the translocation of iron. The staining and manganese concretions in the lower B horizon of some of the peaty gleyed podzols probably represent manganese moved under similar conditions to the iron but differences in the conditions required for immobilisation of the two metals has caused a vertical separation. This may mean that the complexes involved in the movement of the manganese do not react as quickly to the 'aerobic' environment when they enter it, as the iron complexes do. The concentrations of manganese would also be lower as there is less available in the parent material and these smaller concentrations may well stay complexed longer, being more stable.

In the case of the manganese concretions found near the soil-limestone interface the manganese would probably be thrown out of solution due to the proximity of the limestone. Manganese is unstable in solution in the presence of high concentrations of calcium cations and the concentrations of these ions would increase rapidly as the limestone surface was approached.

Great difficulty is encountered when considering factors controlling the immobilisation of manganese in very stony materials where the very hard pan was produced. As mentioned earlier (p.356) this kind of pan was found close to or below the water table. In the case of immobilisation below the water table it is extremely difficult to imagine conditions existing whereby oxidation could take place. The water table could have been somewhat lower in the past and the pan be a fossil feature. If this were the case it would still be difficult to explain why the material of the pan had not been reduced and mobilised after the rise of the water table. The significant factor seems to be that in every case the material cemented is extremely stony so that it forms a bed of gravel of a lens of gravelly material. This gravelly nature would make it extremely free draining when it was above the water table. A lense of gravelly material within a more impervious material would act like a natural well with water moving into it from the surrounding material. If the lens were near the water table then water may well drain into it and then dry out. During such a drying out manganese in solution would be precipitated and due to preferential flow into the material concentration of manganese could take place. Absolute drying out of the water in the gravel area might not even be necessary as Eh conditions may be sufficiently different to cause the manganese to be thrown out of solution.

Peaty Gleyed Podzol.

Profile no. : 17 P.G.P. Sample numbers : W. 1-5

Location : The northern end of Knock Fell.

Nat. Grid Reference : 716312

Altitude : 2450ft. O.D.

Relief and aspect : A narrow ridge with a gentle slope to the north west.

Geological data : The profile is developed in a layer of superficial material overlying the Great Limestone.

Vegetation : Nardetum sub-alpinum.

Horizon: ins	
L	Trace.
F	Brown black; plant remains clearly visible.
$6\frac{1}{2}$ - 5" H	Black, crumbly peat; many roots; sharp, regular boundary.
5" - 0 A	
0 - $1\frac{1}{2}$"	Grey black (10YR 4/1), friable loam; few stones; high organic matter content; strong, moderate crumb; abundant roots; gradual regular boundary.
A_{2G} $1\frac{1}{2}$" - 3"	grey (10YR 3/1), stony, friable loam; weak, coarse prismatic which breaks down to moderate, fine crumb; frequent roots; dark, organic staining along very fractures; sharp, highly irregular boundary.

B_2	(5YR 4/8), friable, clay loam; moderate
3½" - 5"	medium blocky; frequent roots; few stones; sharp, irregular boundary.
B_{PAN}	Up to ⅛" iron pan; brittle, black, vitreous looking fracture faces; usually at the base of B_2 but may be within the B_2.
C	(10YR 3/2), firm, stony clay loam; weak,
5" - 12"	moderate blocky; few roots; the lower ½" of this horizon is often stained black brown, as is the upper surface of the limestone; the upper surface of the limestone is fragmented and embedded in the soil; sharp, irregular boundary.
D	Limestone bedrock.

Profile no. 17 P.G.P.

Sample no.	Depth.	p. H.	$CaCO_3$%
W 1.	0 - 1	3.9	0
W 2.	2 - 6	4.2	0
W 4.	7 - 9	4.25	0
W 5.	11 - 15	5.1	0

	U.S.Sand	I.Sand	I.Silt	Clay	U.S. Silt %
W 1.	26.7	45.7	23.6	30.7	42.6
W 2.	21.5	36.5	21.2	42.4	36.0
W 4.	0.4	14.9	30.7	54.4	45.2
W 5.	19.9	42.5	26.7	30.80	49.3

	% B.S.	Extractable Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
W 1.	15	0.6	0.6	0.38	0.11	13.37	4.5	0.5	7.0
W 2.	12	0.6	0.5	0.37	0.12	7.07	1.5	0.2	7.5
W 4.	11	0.65	0.4	0.33	0.11	6.58	1.26	0.09	14.0
W 5.	39	3.6	2.0	0.45	0.15	6.08	1 .03	0.04	25.75

meq./100g

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O %
W 1.	65.50	16.14	1.79	0.37	0.49	0.62	1.13	0.75	0.03	9.16
W 2.	67.82	18.69	1.60	0.46	0.48	0.63	1.49	0.78	0.03	6.67
W 4.	64.40	18.21	5.53	0.75	0.49	0.63	2.08	0.86	0.04	5.77
W 5.	66.82	17.66	4.09	0.65	0.71	0.69	1.86	0.73	0.11	5.71

<u>Peaty Gleyed Podzol</u>

Profile no : 18 P.G.P. Sample no's : W. 21,22,23 and 24.

Location : To the south of the "Radar Road".

Nat. Grid Reference : 707303

Altitude : 1850ft. O.D.

Relief and aspect : Gradual slope to the north west.

Geological data : The soil is developed in superficial material overlying the Whin Sill.

Vegetation : <u>Nardetum sub-alpinum.</u>

Horizon : ins.	
$8\frac{1}{2}$ - 8 L	Mainly <u>Nardus</u> leaves.
8 - 7 F	Wet, brown; mainly grass blades.
7 - 0 H	Black, damp, friable peaty humus; sharp regular boundary.
0 - 2 A_{2G}	Dark grey brown, friable to firm, stony loam; weak, medium crumb; frequent live roots; sharp, regular boundary.
B_{PAN}	Very thin (Up to $\frac{1}{8}$") dark red brown (2.5YR 3/4), but does not form a barrier to roots or drainage; some accumulation of organic matter just above the pan plus a slight root mat; sharp, regular boundary.

B_2 2 - 9	Dark reddich brown (5YR 3/3), friable, very stony loam; medium, moderate crumb; frequent live roots; freely drained; merging, regular boundary.
B_3 9 - 16	Dark reddish brown (5YR 3/4), friable very stony loam; medium moderate crumb; occassional live roots; freely drained; gradual, regular boundary.
C 16 - 33+	Brown (7.5YR 4/4), friable, extremely stony, loam; a marked increase in size and number of boulder below 16", all the boulders are Whin Sill; this horizon is really Whin Sill boulders with loam between.

Profile no. 18 P.G.P.

Sample no	Depth (ins)	p.H.	$CaCO_3$%
W.21	0 - 2	4.1	0
W.22	5 - 7	4.4	0
W.23	11 - 13	4.8	0
W.24	19 - 21	5.0	0

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
W.21	42.1	57.7	15.6	26.7	31.2
W.22	51.2	62.3	15.5	22.2	26.6
W.23	50.7	69.5	16.4	14.1	35.2
W.24	59.1	75.0	11.4	13.6	27.3

		Extractable							
	% B.S.	Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
W.21	7	0.74	0.4	0.33	0.07	10.03	2.48	0.5	4.96
W.22	13	0.6	0.25	0.37	0.06	8.12	2.00	0.03	6.66
W.23	15	0.53	0.04	0.45	0.06	7.04	1.48	0.06	24.66
W.24	21	0.48	0.43	0.49	0.08	7.87	1.88	n.d.	n.d.
		meq./100g							

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O %
W.21	75.51	7.19	2.09	0.23	0.59	0.80	0.74	6.24	0.05	4.32
W.22	65.93	8.50	8.79	1.07	0.79	0.75	0.81	4.38	0.19	6.78
W.23	51.31	17.22	8.59	2.03	0.69	0.72	0.70	8.17	0.13	9.14
W.24	51.06	16.30	8.68	2.14	0.62	0.67	0.68	8.95	0.14	9.12

Peaty Gleyed Podzol

Profile no. 19 P.G.P. Sample no's : W. 34, 35, 36 & 37.

Location : Eighty yards south of Knock Ore Gill.

Nat. Grid Reference : 696298

Altitude : 1250ft. O.D.

Relief and aspect : A 15^{o} slope to the north west to Knock Ore Gill.

Geological data : A thick layer of superficial material overlies the Basement Series of the local Carboniferous.

Vegetation : Nardetum sub-alpinum.

Horizon: ins	
$9\frac{1}{4}$ - 9	
L	
9 - 8	Mainly Nardus leaves.
F	
8 - 0	Black, wet, greasy peat; sharp regular boundary.
H	
0 - 6(8) A_{2G}	Brown (7.5YR 5/2), firm, very stony loam; weak, moderated blocky; frequent live roots; almost a platform of large stones near the base of the horizon; low organic matter content; no mottles; sharp, irregular boundary.
B_{PAN}	Up to $\frac{1}{4}$" iron pan; root mat on the upper surface; very sinuous; continuous; sharp, irregular boundary.

6 - 7 B_2	Reddish brown(5YR 4/4), firm, very stony clay loam; weak medium blocky; no roots, low organic matter; no mottles; clear, irregular boundary.
7 - 11 B_3	Grey (5YR 5/1), firm, stony clay; very weak coarse blocky; no roots; low organic matter content; frequent medium distinct yellowish red (5YR 5/8) mottles; gradual regular boundary.
11 - 24+ C	Grey brown (10YR 5/2), firm, stony clay loam to clay; structureless - massive; no roots; frequent medium, distinct, strong brown (7.5YR 5/6) mottles.

Profile no. 19 P.G.P.

Sample no.	Depth (ins)	pH	$CaCO_3$
W.34	1 - 3	4.1	0
W.35	6 - 8	4.8	0
W.36	10 - 12	4.9	0
W.37	18 - 20	5.3	0

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
W.34	44.1	58.6	14.5	26.9	29.90
W.35	33.7	48.7	17.1	34.2	32.1
W.36	19.8	34.5	23.2	42.2	38.00
W.37	22.8	37.3	22.8	39.9	37.3

Extractable

	% B.S.	Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
W.34	7	0.6	0.04	0.35	0.1	3.63	0	0.3	-
W.35	8	0.35	0.04	0.35	0.09	5.99	0.98	0.16	6.13
W.36	16	0.49	0.04	0.35	0.16	5.24	0.62	0.07	8.86
W.37	12	0.39	0.09	0.37	0.18	5.39	1.25	0.09	13.89

meq./100g

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O %
W.34	84.60	7.78	1.40	0.18	0.50	0.66	1.25	0.91	0.03	2.70
W.35	81.95	4.90	5.26	0.81	0.58	0.84	2.44	2.07	0.05	9.38
W.36	65.08	18.70	5.30	0.58	0.50	0.69	1.65	0.82	0.05	6.05
W.37	64.13	19.18	5.24	0.48	0.50	0.70	1.68	0.77	0.07	6.10

Peaty Gleyed Podzol

Profile no : 20 P.G.P. Sample no's : B.H. 5-7.

Location : The eastern slopes of Burnt Hill.

Nat. Grid. Reference : 756328

Altitude : 1825 ft.

Relief and aspect : An almost level bench with an easterly aspect.

Geological data : A thick layer of drift overlying the Tyne Bottom Limestone.

Vegetation : Callunetum.

Horizons :

ins	
L	Trace
8 - 0 H	Black, greasy massive peat ; sharp regular boundary.
A_{2G} D - $2\frac{1}{2}$	Dark grey (10YR 4/1), very stony, plastic weak, moderate blocky ; few roots ; low organic matter content ; sharp, irregular boundary.
B_{PAN} $2\frac{1}{2}$ - $2\frac{3}{4}$	The upper surface is blackened and carries a root mat; below this blackened layer the colour is dark red brown and below this orange; few roots penetrate the brittle pan; sharp, irregular boundary.
B_2	

$2\frac{3}{4}$ - $6\frac{3}{4}$ ($10\frac{3}{4}$)	Dark yellowish brown (10YR 5/4), very stony, plastic ; very weak, coarse blocky; very few roots; low organic matter content; merging, highly irregular boundary.
B $6\frac{3}{4}$ ($10\frac{3}{4}$) - $10\frac{3}{4}$ ($14\frac{3}{4}$)	Discontinuous dark yellowish brown (10YR 5/4) with black staining on pebbles, pebble lenses; strongly cemented and must be broken with a hammer; no roots ; no organic matter.
C $10\frac{3}{4}$ - 24+	Dark grey brown (10YR 4/2), very stony, plastic ; structureless, massive; no roots; no organic matter.

Profile no. 20 P.G.P.

Sample no.	Depth (ins)	p H.	$CaCO_3$%
BH 5	0 - 2	3.8	0
BH 6	3 - 6	4.2	0
BH 7	8 - 12	4.3	0

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
BH 5	50.0	64.6	12.5	22.9	27.1
BH 6	47.6	59.5	14.3	26.2	26.2
BH 7	40.3	58.4	11.8	31.8	27.9

	% B.S.	Extractable Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
BH 5	3	0.13	0.1	0.08	0.09	5.30	1.8	0.097	18.5
BH 6	5	0.17	0.15	0.075	0.089	3.30	1.4	0.032	43.9
BH 7	9	0.18	0.14	0.09	0.10	4.82	1.7	0.060	28.3
		meq./100g							

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O	P %
BH 5	n.d.	3.1	0.3	0.10	0.05	0.14	0.58	n.d.	0.008	n.d.	0.026
BH 6	n.d.	4.0	4.2	0.19	0.18	0.21	0.91	n.d.	0.033	n.d.	0.052
BH 7	n.d.	6.5	5.9	0.35	0.18	0.40	1.42	n.d.	0.058	n.d.	0.065

CHAPTER 18

Podzolic Soils

This soil-group, as used here, includes a variety of soils which seem to be transitional between a brown earth and a podzol. Some of the included soils are similar to the brown podzolic soils which have been described by Ball, and the acid brown earths of Burnham and Macknay (1964). Others are the early stages in the formation of a peaty gleyed podzol and are probably similar to the "podzols with gleying" described from south Wales by Crampton (1963).

The soils which are similar to the brown podzolic soils of Ball (1966) are very closely related to the high level acid brown earths developed on the Reserve (p. 417). Their general morphology is very similar and the two often occur as complexes. They are developed in a layer of superficial material resting on various rocks of the local Carboniferous succession. The main areas of this type are associated with the features due to the thicker limestones and are found at the crest or foot of the feature, and the steep valley sides. A surface accumulation of humus is often present and this may be a mull like mor or a mor. In a few cases this surface accumulation reaches a considerable thickness and then has the appearance of a peat mat. Humic material is mixed into the upper mineral soil so producing an A_1 horizon. The separation of the surface humus and the mineral soil with virtually no mixing would seem to be an important stage in the transition to a peaty gleyed podzol in this area. The A_1 is usually thin, 1" - 2", and has a fairly sharp boundary. This is no obvious development of an A_2 horizon. Detailed examination of the soil sometimes reveals lighter coloured patches immediately below the A_1

Plate 70. "Brown Podzolic Soil" beneath
Pterideturne Profile 21 B.P.S.

which resemble faint mottles. This is obviously the early stages in the development of a true A_2 but in this type of brown podzolic soil it is the exception rather than the rule.

A commoner feature is a greying of the lower part of the humic surface horizon. The resultant profile consists of a black or brown black zone underlain by a grey black area which in turn gives way to the (B) (or B) horizon. The change within the humic horizon is gradual and may be a gradual increase in the mineral content with a parallel decrease in humus. The quartz grains in this grey-black area are all bleached. The lower part of the A horizon may also show signs of gleying.

The most marked variation from the acid brown earths is in the colour of the (B) or B horizon. This is much brighter than in the case of the acid brown earths and has a distinct reddish hue. The colours are characteristically 5YR whereas the acid brown earths have a 7YR colour. This reddish colour would appear to reflect the higher content of "free iron" in these soils as compared to the brown earths. This iron could be translocated from the A horizon as in a more conventional podzol but in this case a more distinct A_2 might be expected. The A_2 may, of course, merely be masked by organic matter integrated into the upper mineral soil. The iron may also be liberated in the B, or (B) horizon itself by weathering. A combination of the two processes may actually be operative but future work to improve present knowledge on this subject would seem to be important. A final possibility is that the brown podzolic soils are restricted to parent materials with a higher iron content but total analysis indicate that acid brown earths and podzolic soils can be developed on chemically similar parent materials, e.g. Table 19.

The C horizon has a brown or yellowish brown colour and is very similar in appearance to that of the acid brown earths. It may be slightly indurated and is commonly very stony. The increase in fines down the profile as noted in the calcareous soils and the acid

Plate 71. Podzolic soil with gleying resting on limestone, Knock Fell.

brown earths may also be present : the origins of this increase have been discussed earlier (p. 401).

The A horizon commonly has a crumb structure and is friable. A rather clear cut change in structure may be found at the A/B interface with a subangular or blocky structure in the B. The C horizon has a weak structure and is often very compacted. Plant roots are rare in the C horizon.

The surface horizons are markedly acid. The p H of the A horizon is around 4.5 and of the B horizon 4.5 - 5.0. The C horizon is less acid and has p.H. values in the range 5.5 - 6.0. The acidity of the surface horizons is reflected in the low percentage base saturation which is usually between 10 and 15 in the A horizon and rarely above 20 in the B. Values may be much higher in the C horizon, up to 40, especially on the steep valley sides where flushing may be operative. As in the high level acid brown earths there is a sharp drop in the organic matter content in moving from the A to the B horizon. A slight increase in organic matter content may take place near the base of profiles showing clay translocation and indicates a similar translocation of organic matter.

A morphological variation of this soil is found associated with the Pteridetum north of Knock Ore Gill (Plate 70). In this soil an A_1 horizon is developed which has a high organic matter content and is usually black in colour and friable. This is underlain by a dark brown A_3 horizon with a much lower organic matter but containing abundant black, lateral Pteridetum rhizomes. The A_3 - B boundary is more gradual than the A_1 - A_3 but is never-the-less clear. The B horizon is reddish brown and more compacted than either of the overlying horizons being rather firm. The structure of the B is usually blocky. The acidity and percentage base saturation are very similar to the soils discussed above. This soil is a

Plate 73. 'Brown podzolic soil' over shale, Knock Fell. (The colours of the (B) horizon are actually much redder).

distinct type of podzolic soil and seems to owe the variation in morphology to its association with a Pteridetum.

A further soil grouped with the Podzolic soils in the present work is very distinct from either of the above types. This soil can be accurately described as an incipient, or immature, peaty gleyed podzol. The classification of this soil is somewhat problematical : its affinities with the peaty gleyed podzols are clear but the writer felt that the immaturity of these soils should be made clear. As noted earlier (p. 385) these soils would seem to be similar to the, 'podzols with gleying' which Crampton has described from South Wales.

These soils may have an A_1 horizon with mull like moder humus or an H horizon of moder with an underlying A_1 horizon. The virtually complete separation of the humus and the mineral soil found in the peaty gleyed podzols is not found and a humus rich mineral horizon is always present. Beneath the humic horizon is a discontinuous, weakly developed A_{2G} horizon. This horizon appears as grey or grey-brown lobate tongues' extending into the B horizon. It is this horizon which characterises these soils and indicates their close association with the peaty gleyed podzols. The tongues of the A_{2G} horizon do not seem to be associated with any texturally distinct areas within the upper soil and it is difficult to determine what controls which areas are depleted of iron and gleyed while surrounding areas are relatively unaltered. There is no evidence in the soils of the prisms with central cup shaped illuviated areas which were described by Crampton (1963) and a structural control of the areas of illuviation would seem to be completely absent.

The B horizon is not as brightly coloured as in the brown podzolic soils and the reddish colours are usually absent with strong browns being more usual. The A_1 - B boundary is clear but where the boundary is A_2 - B it is less clear and generally merging or gradual. The B-C boundary is also a merging one. The C horizon is normally brown or yellowish brown but in examples overlying limestone the lower part of the C may be stained very dark brown by translocated organic matter. Clay movement is also sometimes present over limestone but is rarely as marked as in the acid brown earths and brown podzolic soils.

The structure of the A horizon is generally a crumb and the horizon is friable. The B horizon has a granular structure and is also usually friable but it may be firm; the discontinuous A_2 horizon resembles the B horizon in texture and structure. The C horizon has a weak structure, usually blocky. Texturally the soils are loams or clays but superimposed onto this is the clay movement down the profile.

The soils are acid but not as acid as the true peaty gleyed podzols. The A horizon has a pH of around 4.8 and this rises to 5.0 and 5.0 - 5.5 in the B and C horizons respectively. The A_2 horizon has a similar pH to the A horizon. The percentage base saturation also rises down the profile. In the A horizon this may be as high as 20 but drops to less than 10 in the A_2 before rising to between 15 and 20 in the B and C horizons.

These soils are clearly intermediate between an acid brown earth and a peaty gleyed podzol but whether it is a natural evolution or whether some factor is needed to cause the change is extremely difficult to determine. The most difficult problem is what determines the location of the tongues of A_2 horizon and what instigates their formation. The podzolic soils with gleying are usually associated with areas of high level acid brown earths and the two soils carry similar vegetation, have a similar texture and similar parent materials. The only indication is that the humic horizon is usually thicker in the podzolic soil than in the brown earth. This may hold more moisture and so lead to the gleying. This being the case it is difficult to see why the A_2 does not develop uniformly but as tongues. Many questions remain to be answered with respect to these soils but they clearly indicate a possible evolution from acid brown earth to peaty gleyed podzol.

Brown Podzolic Soil

Profile no : 21 B.P.S. Sample no's : W. 25 - 28.

Location : Approx 100 yards north of Knock Ore Gill and 200 yards east of the Fell Wall.

Nat. Grid Reference : 698302

Altitude : 1250 ft. O D.

Relief and aspect : A 15° slope with a south westerly aspect.

Geological data : A thick layer of superficial material overlies the basement series on the Carboniferous.

Vegetation : <u>Pteridetum</u>.

Horizon :

ins.

1½ - 1 L	Mainly bracken debris.
1 - 0 F	Brown, wet, plant remains recognisable.
0 - 2 A_1	Black (5YR 2/1), friable loam; moderate, medium crumb; abundant roots; moderate to high organic matter content; clear, regular boundary.
2 - 7 A_3	Dark reddish brown (5YR 3/2), friable to firm, stony loam; moderate to strong, medium polyhedral; abundant roots and bracken rhizomes; moderate organic matter content; sharp, highly irregular (Tongues of this horizon reach into the horizon below) boundary.
7 - 16 B	Reddish brown (5YR 4/4), firm, stony loam; moderate medium polyhedral; occasional roots to 13"; low organic matter content; gradual regular boundary.

16 - 34+ C	Dark brown (7.5 YR 4/4), firm to very firm, very stony loam; weak, coarse blocky; low organic matter content.

Profile no. 21 B.P.S.

Sample no.	Depth (ins)	p.H	$CaCO_3$	free Fe_2O_3 %
W.25	2 - 5	4.8	0	0.9
W.26	9 - 13	4.7	0	2.6
W.27	20 - 24	5.1	0	3.0
W.28	30 - 34	5.6	0	1.2

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
W.25	39.2	51.7	18.9	29.4	31.5
W.26	46.4	57.8	15.4	26.8	26.8
W.27	51.3	73.5	4.4	22.1	26.6
W.28	56.9	65.3	10.2	24.5	18.6

		Extractable							
	%B.S.	Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
W.25	36	7.4	0.85	0.45	0.56	8.56	2.21	0.58	3.8
W.26	10	0.25	0.13	0.37	0.12	3.64	0	0.13	-
W.27	21	0.35	0.09	0.37	0.11	2.73	0	n.d.	
W.28	15	0.39	0.04	0.35	0.12	3.30	0	n.d.	
		meq./100g.							

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O %
W.25	80.33	6.25	3.31	0.23	0.53	0.70	1.28	0.64	0.16	4.34
W.26	69.81	16.30	4.33	0.67	0.50	0.66	2.70	0.62	0.09	4.34
W.27	76.78	11.76	3.65	0.62	0.51	0.66	2.24	0.47	0.13	3.20
W.28	76.61	10.90	3.59	0.72	0.52	0.66	2.18	0.47	0.13	4.23

Brown Podzolic Soil

Profile no : 22 B.P.S. Sample no's : W. 52 - 56.

Location : The northern slopes of Knock Ore Gill.

Nat.Grid.Reference : 703303.

Altitude : 1550 ft. O.D.

Relief and aspect : A 25^{o} slope with a south south westerly aspect.

Geological data : A thick layer of superficial material overlying the Melmerby Scar Limestone.

Vegetation : Nardetum sub-alpinum.

Horizon : ins	
$\frac{1}{4}$ - 0	Recent plant debris
L	
0 - $1\frac{1}{2}$ A_1	Dark brown (7.5 YR 4/4), friable loam; moderate medium crumb; dense root mat; moderate organic matter content; sharp, regular boundary.
$1\frac{1}{2}$ - 13 B	Yellowish-red (5YR 4/6), friable, stony loam; moderate, medium crumb; frequent live roots; low organic matter content; merging regular boundary.
13 - 25 C	Reddish brown (5YR 4/4), firm to very firm, stony loam; weak, coarse blocky; very few roots; low organic matter content.
25+	The material is very similar to the above but is indurated.

Profile no. 22 B.P.S.

Sample no.	Depth (ins)	pH	$CaCO_3$%	Free Fe_2O_3 %
W.52	0 - 2	4.75	0	1.3
W.53	4 - 6	4.9	0	4.5
W.54	8 - 12	5.0	0	3.7
W.55	14 - 18	5.0	0	1.8
W.56	24 - 28	5.8	0	n.d.

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
W.52	29.7	46.2	21.7	32.1	38.2
W.53	32.0	46.3	22.0	31.7	36.3
W.54	31.3	44.7	24.3	31.0	37.7
W.55	31.7	45.2	18.6	36.2	32.1
W.56	43.0	27.8	15.7	41.3	30.9

		Extractable							
	% B.S.	Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
W.52	8	0.55	0.17	0.35	0.32	10.19	2.98	0.41	7.3
W.53	15	0.88	0.38	0.35	0.32	6.15	1.06	0.20	5.3
W.54	32	0.95	3.02	0.44	0.29	6.65	1.30	n.d.	
W.55	29	2.3	1.45	0.42	0.20	3.48	0	n.d.	
W.56	34	4.81	1.40	0.45	0.22	4.22	0.25	n.d.	
		meq./100g.							

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O %
W.52	69.34	12.12	4.66	0.47	0.52	0.67	1.76	0.87	0.11	6.41
W.53	62.63	18.79	6.16	0.66	0.49	0.66	2.20	1.03	0.15	6.10
W.54	64.18	18.94	4.88	0.94	0.56	0.66	1.84	0.73	0.08	6.01
W.55	61.87	20.98	5.40	0.96	0.58	0.64	3.69	0.95	0.14	4.80
W.56	66.44	17.33	5.46	0.84	0.60	0.65	2.46	0.76	0.11	5.16

CHAPTER 19

Calcareous Soils

The rendzinas and brown calcareous soils are grouped together in this section. These soils are essentially similar throughout the Reserve and have been described from the areas of limestone grassland which lie east of the summit ridge (p.141). This chapter will concentrate on the differences found in the limestone soils over the Reserve.

The brown calcareous soils occupy a much larger area than the rendzinas but they are usually found together as part of a rapidly varying soil complex. As an acid brown earth is also often present the soils of the complex are similar to those found on the areas of limestone grassland on the eastern slopes of the Reserve. The distribution of the soils within the complex follows rather different patterns on the western escarpment: this will be discussed again later (Chapter 24). The calcareous soils are associated closely with limestone outcrops, but as on the slopes east of the summit ridge (p.243), not all the limestones of the local Carboniferous succession form a distinct enough feature to outcrop. The thinner limestones are concealed below a blanket of drift or colluvium which is too thick for the limestone bedrock to exert a controlling influence on the character of the soil. The following limestones form extensive outcrops and hence have calacareous soils associated with them on the western slopes:-

Melmerby Scar Limestone, Scar Limestone, Four Fathom Limestone and the Great Limestone. The Great and the Melmerby Scar Limestones give by far the largest outcrop and two belts of calcareous soils associated with these are found between 2400 and 2500 feet, and 1500 and 1600 feet respectively. The vegetation associated with these soils is similar to that of the limestone grassland areas on the east of the Reserve and is an _Agrosto - Festucetum._

Most of the limestone outcrops on the western escarpment are the faces of scars and hence slopes of varying angles, but commonly steep. As a result most of the areas of calcareous soils on the escarpment are also associated with steep slopes. At the top and bottom of the scars the cover of superficial material usually thickens rapidly so sealing off the limestone. Only the Great Limestone forms extensive areas of level, or nearly so, ground with a thin enough cover of superficial cover for the limestone to dominate the soil : these areas are on Knock Fell and Green Castle.

A feature of the soils on the escarpment which may be a result of the sloping sites is the greater depth of each sub-group when compared to those on the east. The rendzinas are up to 9" deep but are still a very dark brown or black colour with a high humus content throughout and a strong crumb structure throughout. The brown calcareous soils are up to 15" deep but, apart from containing abundant large limestone fragments throughout the profile, are similar to those found to the east. The depths of the members of each sub-group on the flatter outcrops of the Great Limestone on Knock Fell are similar to those discussed for the limestone grassland sites to the east (p. 141).

These soils on the sloping sites are invariably stony; most of the stones are limestone but a few sandstone fragments and, downslope of its outcrop, Whin Sill fragments may be present. The stones are present throughout the profile. This greater stoniness may be due to the increased instability of sloping sites causing a greater mixing of the bedrock into the soil. Mechanical analysis showed an increase in fines down the profiles of most of the rendzinas and brown calcareous soils on sloping sites. This too may be a consequence of the sloping sites. There are three possible explanations to this increase in fines. The underlying limestone will ensure free drainage in the soils but the slope will add a lateral component to the drainage and make it excessive: the increase in fines may be a result of the excessive drainage carrying the fines down the profile. If the parent material were layered this could also explain the increase in fines. This would seem unlikely as the clay mineral types remain constant down the profile and the chemistry does not differ markedly : this would necessitate both layers of parent material being derived from the same source. Finally the increase in fines down the profile may really indicate a depletion in fines in the A horizon with no addition to the B and C. In this case the lower horizons would then indicate the original clay and silt contents of the parent material. The fines could be removed from the A horizon by slope wash : this would be expected on the steep slopes. This latter explanation would explain the higher fines content of the C horizon better than a downward movement within the profile. An actual increase in fines in the C by translocation of clays would infer a textural C horizon.

Soils in which the increase in clay content continues down the profile instead of being restricted to the B horizon have been reported from several other localities. Crampton (1964) describes them overlying Carboniferous Limestone in Glamorgan and after micromorphological studies he showed movement of clay down the profile. An increase in organic matter at the base of the profile was also reported by Crampton (ibid) and he suggests that this is due to translocation of organic matter along with the clay. A similar increase in organic matter was noted in acid brown earths on the escarpment and is referred to again later. Crampton (ibid) concludes that the increase in clay content is a result of translocation. It is significant that the profiles considered by Crampton are on level, or only slightly sloping sites, and so slope wash will be at a minimum.

Bartelli and Odell (1960) discussing a similar formation of textural horizons suggest that the high calcium ion content in the zone of clay enrichment close to the calcareous bedrock or drift may cause precipitation of colloids. As the movement is of the finest

Plate 74. Brown calcareous soil over the Melmerby Scar Limestone. Profile 25 B.C.S.

fraction of the clay (Bartelli and Odell ibid) this could be extremely important. The high calcium ion concentration would undoubtedly be present at the base of the profiles overlying limestone at Moor House. On the evidence of this type of work it would seem that increases in clay content at, or near, the base of a profile can be caused by translocation of clay grade material.

This mechanism is probably operative in the soils in question as the underlying limestone will ensure free to excessive drainage. In addition slopewash will almost certainly be operative on these sloping sites and so some clay grade material will undoubtedly be being removed downslope by this process. Which of the two process i.e. translocation or slopewash, plays the greatest part in giving the resultant distribution pattern of the clay is extremely difficult to determine. It is a little surprising that similar textural horizons are not more extensive in the soils developed over limestone on the eastern slopes. The increase in fines near the base of the deeper profiles, i.e. acid brown earths, on Hard Hill - Eastern Unit (p. 198) and the low content of fines on the tops of the mounds on the Rough Sike Site could certainly be due to movement of clays down the profile. The 'layering' of superficial material on the Moss Burn - Sheep Fold Site is unlikely to be due to clay movement as a change in the stone type and content is also present (p. 197). The eastern sites are all level or have low slopes and it is tempting to suggest that the steep slopes of the escarpment are the factor controlling the distribution pattern within the profiles on these slopes. Micromorphological studies now in progress may provide further evidence but at present one can only say that both translocation and slopewash are almost certainly operative and that other workers have shown that clay translocation can give similar textural horizons.

The pattern of distribution of the rendzinas and brown calcareous soils is controlled by the depth of material overlying the limestone in the same way as on the limestone grassland sites of the eastern slopes. The closest similarity to the eastern grassland sites is found on the flat outcrops of the Great Limestone on Knock Fell; here complexes are found which are very similar to those studied in Part II. It should be pointed out that the calcareous soils are only found where some factor has caused a thinning, or prevented the accumulation, of the superficial material which is usually present. This type of situation may be found close to shake holes or sudden changes in level of the limestone surface.

Chemically the soils are very similar to the calcareous soils of the grassland sites studied in Part II. The pH values are very similar with values between 6.0 and 6.5. Free carbonates are present in rendzinas and brown calcareous soils and the values tend to be slightly higher on the slopes than in the eastern sites, e.g. up to 4% in the rendzinas and 3% in the brown calcareous soils. These slightly higher values may be due to the greater mixing of limestone bedrock on slopes. Percentage base saturation values are also similar to those discussed for the eastern sites, i.e. 70 - 90% for the rendzinas and 50 - 70% for the brown calcareous soils, but the soils on the steep slopes tend to fall near the lower end of these ranges and indicate the greater leaching on the sloping sites. Earthworms are present throughout the profiles and will help to keep the calcium content of the soil high by continual mixing of the soil. Texturally the soils are varied but the clay and silt contents are invariably high giving over 25% clay and 25% silt. A result of these is that the blocky structure sometimes present in the (B) horizon of the brown calcareous soils on the eastern sites is almost always present on the escarpment. A blocky structure may also be present in the deepest rendzinas.

Other very localised soil types can be found associated with the limestone outcrops. In places actual cliffs form on the limestone scars, particularly the Melmerby Scar Limestone, and small ledges are found on these 'cliffs' on which soil development has taken place. On these ledges the soil which has formed has an extremely high humus content with very little mineral contribution. Although these soils have not been examined in detail they obviously represent the beginnings of a true sedentary soil and must be equivalent to Duchaufour and Bartole's (1966) lithosol a humus brut or sol humique carbonaté.

As with the areas east of the summit ridge the complexes of which the rendzinas and brown calcareous soils form part are roughly equivalent to the areas of 'red brown limestone soil' as mapped by Johnson (Johnson and Dunham 1963). One area mapped as this type by Johnson (ibid) does not fit in with the soil types described above by the present writer. This particular area, is on the Tyne Bottom Limestone on the northern slopes of Knock Ore Gill (Grid reference 707305). The site in question is a very small level bench which forms a marked break in the steep slopes. The soil developed on this bench is a uniform black colour and is up to 15" deep. The soil is always extremely wet and, despite the underlying limestone, water accumulates in the bottom of a pit. There would seem to be a continuous seepage of water across the bench from that part of the limestone outcrop which stands upslope of it. The humus content is extremely high and undoubtably a result of the extremely wet conditions which prevail, but the humus seems well integrated and is not of a true mor type. This soil type has not been studied in detail but it is undoubtably a result of the flushing and very different to the normal calcareous soils. This soil is best designated as a calcareous gley.

Rendzina

Profile no : 23 R   Sample no. : W.6

Location : North east edge of Knock Fell.

Nat. Grid Reference : 716311

Altitude : 2450ft. O.D.

Relief and aspect : A gentle slope to the north east, to the col between Knock Fell and Green Fell.

Geological data : Bedrock is the Great Limestone.

Vegetation : Agrosto-Festucetum.

Horizon : ins.	
A 0 - 2" (6")	Very dark brown black (10YR 2/2), friable, stony loam; strong medium to fine crumb; freely drained; dense mat of living roots; high organic matter content; earthworms present; sharp boundary.
C	Fragmented bedrock limestone with a trace of soil between the blocks.

Profile 23 R.

Sample no.	Depth (ins)	p H	$CaCO_3$ %
W.6	0 - 3	6.4	1.2

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
W.6	27.8	41.3	20.3	38.4	33.8

Extractable

	% B.S.	Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
W.6	Sat.	13.7	1.13	0.47	0.23	14.45	4.59	1.04	4.41

meq./100 g.

1407

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O %
W.6	74.19	6.60	4.45	0.33	0.85	0.71	0.86	1.52	0.15	8.15

Brown Calcareous Soil.

Profile no. 24 B.C.S. Sample no's : W. 10 and 11.

Location : Northern end of Knock Fell.

Nat. Grid Reference : 716311

Altitude : 2450ft. O.D.

Relief and aspect : A gentle slope to the north east.

Geological data : The Great Limestone is bedrock.

Vegetation: Agrosto - Festucetum.

Horizon: ins	
0 - 4 A	Very dark grey brown (10YR 3/2), friable clay loam; strong fine crumb; abundant live roots; very few stones; moderate organic matter content; irregular gradual boundary.
4 - 8 (B)	Very dark brown (10YR 2/2), friable to firm clay loam; strong medium crumb; frequence live roots; moderate organic matter content; few stones; sharp irregular boundary.
9 - 13+ C	Zone of fragmented limestone bedrock with clay loam between the boulders; the soil-limestone interface is stained black.

Profile no. 24 B.C.S.

Sample no.	Depth (ins)	pH	$CaCO_3$%
W.7	0 - 3	5.8	0.75
W.8	5 - 8	6.4	1.1

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
W.7	33.3	48.4	15.0	36.6	30.1
W.8	43.8	52.0	18.8	29.2	27.0

		Extractable							
	% B.S.	Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
W.7	39	0.53	0.21	0.35	0.14	10.46	3.12	0.41	7.61
W.8	71	8.65	0.41	0.42	0.13	10.27	2.90	0.32	9.06
		meq./100g.							

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O %
W.7	69.56	11.49	6.26	0.41	0.52	0.69	1.11	0.62	0.22	6.01
W.8	61.08	17.85	6.52	0.69	0.65	0.65	1.47	0.55	0.37	7.26

Brown Calcareous Soil

Profile no : 25 B.C.S.   Sample no's : W. 10 and 11.

Location : About 100 yards north of the Ministry of Aviation access road and 100 yards east of the fell wall.

Nat. Grid Reference : 697297

Altitude : 1450ft. O.D.

Relief and aspect : A 19^{o} slope facing west south west.

Geological data : Bedrock is the Melmerby Scar Limestone.

Vegetation : Agrosto - Festucetum.

Horizon: ins	
0 - 3 A	Very dark grey brown (10YR 3/2), friable, clay loam; strong medium to fine crumb; dense root mat; moderate to high organic matter content; earthworms; very few stones; gradual, regular boundary.
3 - 9 (12) (B)	Dark brown (10YR 4/3), friable to firm, clay loam; strong medium polyhedral; abundant live roots; moderate organic matter content; earthworms; clear, irregular boundary.
9+ C	Limestone with clay loam along fractures. Limestone with

Profile no. 25 B.C.S.

Sample no.	Depth (ins)	p H	$CaCO_3$%
W.10	0 - 3	5.9	0.5
W.11	5 - 8	6.6	1.3

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
W.10	31.8	40.6	15.4	44.00	24.1
W.11	32.4	43.0	25.3	31.7	35.9

	% B.S.	Extractable Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
W.10	56	11.1	1.02	0.47	0.45	10.88	3.31	0.52	6.37
W.11	82	14.2	0.57	0.47	0.34	7.82	1.86	0.39	4.77

meq./100g.

	Si	Al	Fe	Mg	Ca	Na	K	Tl	Mn	H_2O%
W.10	67.71	15.16	4.67	0.20	0.61	0.63	1.07	0.67	0.10	6.04
W.11	66.87	16.62	4.98	0.24	0.72	0.63	1.14	0.87	0.12	5.96

CHAPTER 20

Brown Ranker

The brown ranker is restricted in occurrence to two small areas on Middle Tongue, in the extreme north west of the Reserve. The name given to this area correctly suggests that it is a spur of ground between two streams, Middle Tongue Beck and Crowdundle Beck. The specific sites under consideration here are close to the confluence of the two streams and lie on the tops of two small, rounded hillocks. The hillocks drop away to river terraces formed when the streams were at some higher level. These soils were mapped as "brown earth soils" by Johnson (Johnson and Dunham 1963), fig.11.

The hillocks are formed by Ordovician age tuff bands (p.21) contained within the Skiddaw slates (p.16) which are found abutting against the base of the Carboniferous in this locality. It seems likely that the more resistant nature of the tuffs, as compared to the slates, explains the upstanding hillocks. The surrounding outcrop of the Ordovician rocks is blanketed under a mantle of superficial material derived mainly from the Carboniferous escarpment. The hillocks in question seem to be free of this mantle. The tops of the hillocks carries a pattern of mounds which give a hummock-hollow surface; some of these mounds may be remnants of a former drift cover (p.23).

The vegetation of the two areas has been mapped as Festucetum (p.61) by Eddy (1963), fig. 9. This vegetation only occupies the tops of these rises and gives way on the slopes to flushes, Pteridetum or Juncetum squarrosi sub-alpinum. The soils on the slopes are peaty gleyed podzols or peaty gleys formed in a thickening superficial cover. Some Juncus squarrosus and Polytricum spp. are found on the mounds on the hillocks and indicate a damper, and more acid, soil than in the hollows between the mounds.

The soils are shallow and extremely stony. A dense root mat is found at the surface. Although the whole soil has a high organic carbon content there is a very marked concentration of humus at the surface, usually in the top one to two inches. The humus is a mull like moder. This surface horizon is black or very dark brown and the colour changes to a dark brown, and sometimes a reddish brown below that, i.e. in the (B) and C horizons. The soil structure is strong throughout the profile and is usually a fine to medium crumb. Although the whole profile is very stony there is a marked increase in stones down the profile. At about 1 ft. from the surface the bedrock is almost undisturbed and there is only a trace of soil material present on the fracture faces of the pieces of rock. The bedrock is split into small rectangular blocks which become less and less disturbed with increasing depth : this is parallel by a decrease in the amount of soil material between the blocks.

The loss on ignition of all the horizons is high but this is especially true of the A_1, about 25%. The surface, organic rich horizon, is very acid, pH 3.5 - 4.0, and the pH of the subsoil is usually below 4.5. The soil is, then, very acid and it is also a leached soil with the percentage base saturation below 30% and usually between 20 and 30%.

Examination of the clay fraction of the soil showed a moderately strong quartz peak but no clay mineral peak. The surrounding drift contains illite which gives moderate to strong peaks. The underlying tuffs contain a little muscovite. The soil contains a moderate content of fines and is a loam. Although one or two sandstone fragments are present almost all the rock fragments found in the soil are fragments of the underlying tuff. These results would seem to indicate that this soil is being formed in situ from the underlying tuff with a very slight addition from transported material. Total chemical analysis tend to confirm this with the soil material of the C horizon showing several similarities to the tuffs but in particular a higher soda content than is usually found on the soils of the escarpment. If the analyses of the C horizon and the underlying tuff are taken as the original composition for the whole soil then aluminium, perhaps in the mica, iron and sodium have been removed from the A, and (B) horizons.

The small mounds present on the site were not sampled for analysis but inspection on the site showed them to be a somewhat deeper soil with a much sharper break at the point at which bedrock comes in strongly. A few sandstone cobbles were also found in the mounds. It is easy to envisage these mounds as the remnants of a former, more extensive, cover of superficial material. It is difficult to imagine the tops of these hummocks free of such a cover when one is present on their slopes. The cover could have been removed by solifluxion at an early date, or by water erosion ; the old river terraces show that the river was formerly at a much higher level.

BROWN RANKER

Profile number : 26 B.R. Samples numbers : W. 46 - 48.

Location : Between Middle Tongue Beck and Crowdundle Beck a quarter of a mile upstream from their confluence.

Nat. Grid Reference: 683318

Altitude : 1250'

Relief and aspect : The pit was on the top of a hillock: there was a 5^{o} slope at the pit site with the slope increasing in all directions.
Aspect - West 35^{o}S.

Vegetation : _Festucetum_. On some small hummocks _Juncus squarrosus_ and _Polytricum_ spp. become important.

Geological data : The bedrock is Ordovician tuffs.

Horizon ins	
A 0 - 1½	Dark brown-black (5YR 2/1), friable, stony loam; strong, very fine crumb; very high humus content; dense root mat; freely drained; merging boundary.
(AB) 1½ - 6"	Dark brown (7.5YR 3/2), even coloured, friable, very stony loam; strong, fine to medium crumb; organic matter content much lower than in the above horizon; frequent roots - these form a root mat on the stone surfaces; freely drained; merging boundary.
C 6" - 9"	Dark reddish brown (5YR 3/4) loam to clay loam, present between the blocks of the highly fragmented bedrock; friable; freely drained; frequent roots. Merges downwards with fragmented rock with no soil between the soil blocks.

Profile no. 26 B.R.

Sample no.	Depth (ins)	p H	$CaCO_3$%
W.46	0 - 2	4.8	0
W.47	4 - 7	4.7	0
W.48	9 - 12	5.2	0

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
W.46	69.7	77.3	7.6	15.1	15.2
W.47	40.6	46.6	23.2	30.2	29.2
W.48	43.6	56.6	21.7	21.7	34.7

		Extractable							
	% B.S.	Ca	Mg	Na	K	L.O.I. %	%C	%N	C/N
W.46	23	0.89	0.81	0.75	0.84	24.17	9.63		
W.47	18	0.47	0.30	0.45	0.30	13.34	4.48		
W.48	26	0.39	0.09	0.45	0.17				
		meq./100g.							

	Si	Al	Fe	Mg	Ca	Na	K	Tl	Mn	H_2O%
W.46	63.04	7.71	4.39	0.25	0.53	1.33	1.25	0.69	0.15	11.48
W.47	66.80	12.78	5.14	0.29	0.52	1.31	1.59	1.04	0.32	5.67
W.48	59.24	18.71	6.03	0.70	0.54	1.61	1.93	1.00	0.27	7.51
W.48A	63.29	19.39	6.40	0.35	0.70	3.39	2.41	1.18	0.26	2.57

9416

CHAPTER 21

Acid Brown Earths

Two sub-groups are dealt with together in this chapter, the acid brown earths and the acid brown earths with gleying. Two main types of acid brown earth are to be found on the Reserve and a gleyed equivalent of each of these can be found. The two types are associated with similar parent materials and are found on similar sites but there is evidence of an altitudinal separation. For this reason they have been designated a normal acid brown earth (or low level acid brown earth), and a high level acid brown earth. The high level acid brown earth is equivalent to the acid brown earths discussed in connection with the limestone grassland sites on the eastern slopes of the Reserve. The vegetation associated with both types is an intergrade between an Agrosto-Festucetum (p.60) and a Nardetum sub-alpinum (p.59). In the high level type Nardus stricta is more important and the vegetation is closer to the Nardetum.

The normal acid brown earth is mainly found associated with the feature caused by the Melmerby Scar Limestone and is commonly at the base of the feature. It is also found on some of the steep sides of the valleys on the escarpment. Both types are found in complexes with rendzinas and brown calcareous soils. The high level type is found on the flat outcrop of the Great Limestone on Knock Fell and is there part of a complex developed in an increasing thickness of superficial material resting on the limestone. Elsewhere the high level type, as the low level type, is found associated with the features caused by the thicker limestones, and with the steep valley sides of the escarpment. When associated with the limestone features they are commonest at the top and bottom of the features.

Plate 75. Low level acid brown earth. Profile 27 A.B.E.
The textural B can be clearly seen.

The most obvious difference between the normal and high level types is in the humus form and the nature of the A - horizon. The normal, or low level, type has a mull humus which is very well integrated into the mineral soil producing a relatively deep, humus rich, A_1 horizon. This A_1 has a dense root mat and a strong, medium to fine crumb structure. This is little, if any, accumulation, of plant debris on the surface. The thickness of the A_1 is usually about 3" and may be up to 6" : the boundary with the underlying B horizon is a merging one. The loss on ignition of the top few inches is around 10%. It is also worth noting that earthworms are common in the upper soil of the normal acid brown earth.

The high level type has been outlined in Part II but some of the features will be summarised here to contrast with the normal type. The humus in the high level type is a mull like moder and is concentrated in a thinner, very dark brown to black, A_1. The integration of mineral soil and humus is much less complete than in the normal type. The structure is much weaker and usually polyhedral. The loss on ignition of the shallow A_1 is similar to that of the A of the normal type but it decreases much more rapidly at the A_1 - B boundary which is much sharper than in the normal type. Earthworms are very rare in the high level type.

The (B) horizon of the two types is rather similar. In both it is brown to reddish brown but the reddish tinges seem to be more common in the high level type. Live roots are found in both but are abundant in the normal type while being common in the high level. The structure of both is blocky or polyhedral but it is stronger and finer in the normal type. The loss on ignition of the normal type is rather higher than that of the low level type, 6 - 7% , at the top of the (B) horizon but at the B-C boundary they have dropped to about the same level, 4% . The B-C boundary is a merging one in both types.

The C horizons are very similar, allowing for variations in parent material from place to place. This horizon is very firm and compacted and may show slight induration : the most accurate picture is probably given by saying that it has a high bulk density. Structure is very weak, coarse blocky if present but the horizon is often massive and structureless. The colour is duller than that of the (B) and is usually a yellow brown. Live roots may be present but are infrequent.

The pH of the surface horizons of the two types is rather different, the high level type being more acid than the normal type. The pH of the surface of the high level is around 5.0 whereas that of the normal type rarely falls below 5.5. The percentage base saturation of the two types also differs with the high level type more heavily leached than normal. Typical values are, normal type 20-40%, and the high level type 10-30%. The lower horizons, i.e. the base of the (B) and the C have chemical properties much more alike with pH values around 6.0 and base saturation values of 10-20%.

Texturally both types varied from a loam to a clay loam and are developed in a layer of superficial material resting on various rocks of the local Carboniferous succession. The origin of the parent material will be considered later (p. 440). Superimposed onto the variation in texture from site to site, due to variations in the parent material, is a textural variation within profiles. This variation is due to a higher content of fines in the (B) and C horizons than in the upper soil. Sometimes the content of fines continues to increase down the entire profile and on other occasions it increases to a certain depth and then remains constant. This increase down the profile is only present to a very limited extent on level sites. This type of textural variation is most marked in those acid brown earths found near the crest of the features caused by the thicker limestones and on the steepest valley sides. It is less marked in those soils found near the base of the features formed by the limestones. Where present it almost certainly has a similar origin to the same feature discussed in the calcareous soils (p.401) i.e. it is due to translocation of fines probably caused by the extremely free drainage. The build of fines is far more marked in the acid brown earths than in the calcareous soils (e.g. Profile 29). An increase in organic matter is sometimes found at, or near, the base of the profile and is almost certainly due to translocation. Both types of acid brown earth are stony to very stony throughout the profile. The stones are predominantly sandstone and, below its outcrop, Whin Sill : this indicates the transported origin of the material.

Another feature in the soils which is a result of the sloping sites is the variation in depth which is encountered. This is shown by all the types of acid brown earth. When the acid brown earth is found on a level site, e.g. as part of the complex on the Great Limestone of Knock Fell, it is of a similar depth to those outlined in the study of the eastern sites, e.g. 12". On the sloping sites the depths are greater and vary as to the position on the slope. Examples on the crests of the features formed by the limestones are about 18" deep while those that the base of the features are up to 3 ft. deep. A similar increase in depth is found down the steep valley sides found on the escarpment.

A gleyed form of both the acid brown earths is to be found. The gleying is almost always restricted to the C horizon. The commonest indication of the impeded drainage is very find ochreous or yellow mottles on a yellow brown ground colour. This type of mottling is commonly found in the soils with very compacted C horizons with a high clay content. It seems to be commoner in the deeper examples than in the shallower ones. Although this is the commonest form of gleying examples are found of much larger and more distinct mottles and even of completely gleyed, blue-grey coloured, C horizons. The uniformly coloured, blue-grey C horizons are only found when the soil is resting on <u>in situ</u> shale or has a C horizon which is composed chiefly of shale fragments. The shale is sufficiently impervious to hold up the normal drainage and may even form a perched water table. The C horizons with very fine mottles are not distinctly different chemically from those without such mottles, but the uniformly gleyed ones have a lower pH e.g. 5.5 - 6.0, and base saturation than the ungleyed acid brown earth.

The inter-relationship of the normal and high level acid brown earth is an interesting problem. Although the high level form is commonest at higher levels it is also found at the same levels as the normal form. The normal form is uncommon at high levels. It seems unlikely that the two types are equivalent to each other with altitude as the differentiating factor. It seems far more likely that they are both members of the same evolutionary sequence, i.e. a sequence of increasing acidity found as one moves from a brown earth to a podzolic soil. The high level acid brown earth is more acid than the normal type and is clearly an intergrade to a podzolic soil. The more acid surface, the lower base saturation and the change in humus from a mull to a mull like mor are all indications of the increased acidity in the high level type.

If the two types are successive stages in an evolutionary trend it is difficult to explain why one is commoner than the other at a given altitude. One cannot entirely rule out the possibility of observational error, but if a given form is dominant at a given altitude it infers that that particular stage in the evolution of the soils must last longer at the given altitude. Alternately it may suggest that at lower altitudes the normal type is a stable, or climax soil unless some external factor caused an increase in acidity, e.g. selective grazing allowing acidophilous species to invade sites, whereas at higher levels more acid soils are the stable phase. This would seem to be possible as the increased rainfall at higher levels will cause an increase in leaching and hence give more acid conditions. The normal acid brown earth may also be a stage in the evolutionary sequence which can be 'artificially' maintained, e.g. by flushing with calcium rich waters.

It is difficult to explain why the normal acid brown earth was not a common soil type on the limestone grassland sites on the eastern slopes. It would be a logical member of the series of soils and one would expect to find it between the brown calcareous soils and the high level acid brown earth. One explanation for its apparent absence may be that the increase in depth of superficial cover which gives the series of soils is rarely gradual and the increase in depth is commonly as a series of steps. Because of this stepping the normal acid brown earth may be absent on the majority of sites.

The present writer is of the opinion that the two types are most probably stages in a sequence of increasing acidity and tendency towards podzolisation. The normal type seems to be the more stable at lower altitudes and hence this stage in the sequence lasts longer at these levels.

Normal Acid Brown Earths

Profile no : 27 A.B.E. Sample no's : W. 12 - 16.

Location : At the base of the Melmerby Scar Limestone feature 100 yards north of the Ministry of Aviation access road.

Nat. Grid Reference : 697297

Altitude : 1425ft. O.D.

Relief and aspect : A 13^{o} slope facing west south west.

Geological data : A layer of superficial material overlying the Melmerby Scar Limestone.

Vegetation : An intergrade between an Agrosto-Festucetum and a Nardus sub-alpinum.

Horizon: ins	
0 - 2 A_1	Very dark brown (10YR 2/2), friable clay loam; strong, medium crumb; moderate organic matter content; dense root mat; frequent earthworms; gradual, regular, boundary.
2 - 6 A_3	Dark grey brown (10YR 3/2), friable stony clay loam; strong; medium crumb; moderate organic matter content; abundant live roots; earthworms; gradual, regular boundary.
6 - 16 (B)t	Dark yellowish brown (10YR 4/4), firm, stony clay loam; moderate, medium polyhedral; frequent live roots; low organic matter content; merging regular boundary.
16 - 39+ C	Brown (10YR 4/3), very firm, stony clay loam; weak, coarse blocky; occassional live roots.

Profile no. 27 A.B.E.

Sample no.	Depth (ins)	p H	$CaCO_3$%	Free Fe_2O_3 %
W.12	1 - 4	5.6	0	1.2
W.13	7 - 10	5.1	0	1.9
W.14	14 - 18	5.3	0	2.3
W.15	20 - 24	5.5	0	1.8
W.16	30 - 33	5.8	0	n.d.

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
W.12	29.6	47.3	20.0	32.7	37.7
W.13	33.2	45.8	22.9	31.3	35.5
W.14	38.0	56.0	18.00	26.0	36.0
W.15	34.4	50.8	14.3	34.9	30.7
W.16	27.5	35.7	18.7	45.6	26.9

		Extractable							
	%B.S.	Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
W.12	12	3.54	0.53	0.38	0.23	9.36	2.59	0.56	4.62
W.13	23	4.73	0.47	0.38	0.12	5.14	0.58	0.43	1.35
W.14	38	5.88	0.47	0.42	0.18	4.16	0.11	0.2	0.55
W.15	57	6.0	0.49	0.38	0.17	3.95	0.10	0.23	0.43
W.16	71	9.3	0.61	0.42	0.18	5.27	0.64	0.17	3.76
		meq./100g.							

	Si	Al	Fe	Mg	Ca	Na	K	Tl	Ma	H_2O%
W.12	71.14	11.86	4.83	0.17	0.56	0.67	1.00	0.99	0.17	5.96
W.13	69.39	13.77	6.95	0.38	0.57	0.71	1.15	0.79	0.13	5.59
W.14	69.65	15.49	5.57	0.53	0.57	0.69	1.47	0.92	0.12	4.90
W.15	62.57	21.10	5.48	0.53	0.57	0.62	1.72	0.98	0.12	6.23
W.16	63.38	20.39	5.17	0.56	0.57	0.64	1.80	0.83	0.11	5.96

High Level Acid Brown Earth

Profile no : 28 A.B.E. Sample no's : W. 40,41 and 42.

Location : Near Sink Beck at the base of the escarpment.

Nat. Grid. Reference : 699293.

Altitude : 1500 ft. O.D.

Relief and aspect : A 15^{o} slope with a south west aspect.

Geological data : The soil is developed in a layer of superficial material resting on the Melmerby Scar Limestone.

Vegetation : Nardetum sub-alpinum

Horizon :
ins.

0 - 1½ A	Very dark grey brown (10YR 3/2), friable clay loam; strong, fine to medium crumb; dense root mat; moderate organic matter content; sharp, regular boundary.
1½ - 10½ B	Reddish brown (5YR 4/4), friable, stony clay loam; strong medium crumb; frequent roots; moderate organic matter content; merging regular boundary.
10½ - 20½ C	Dark brown (7.5 YR 4/4), firm, stony clay loam; moderate medium blocky; occasional roots; low organic matter content; stonier than the above horizon; gradual regular boundary.
20½ - 26(30) C	Dark brown (7.5 YR 4/2), very firm, very stony clay; massive; occasional roots; low organic matter content; sharp irregular boundary.
26 (30)+ D	Limestone bedrock.

Profile no. 28 A.B.E.

Sample no.	Depth (ins)	p H.	$CaCO_3$	Free Fe_2O_3 %
W.40	2 - 6	5.1	0	2.4
W.41	10 - 13	5.9	0	3.1
W.42	18 - 22	6.0	0	2.7

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
W.40	38.4	48.7	16.4	34.9	26.7
W.41	37.1	47.6	12.6	39.8	23.1
W.42	29.2	37.5	12.5	50.0	20.8

		Extractable							
	%B.S.	Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
W.40	9	0.56	0.09	0.38	0.16	8.99	2.41	0.3	8.03
W.41	26	3.25	0.77	0.63	0.14	6.41	1.18	0.1	11.8
W.42	50	12.5	1.02	0.45	0.18	9.61	2.70	0.09	30.0
		meq./100g.							

	Si	Al	Fe	Mg	Ca	Na	K	Tl	Mn	H_2O%
W.40	69.29	12.90	5.12	0.18	0.52	0.64	0.87	1.24	0.18	6.71
W.41	61.14	20.00	6.5	0.39	0.52	0.62	1.03	0.92	0.13	7.19
W.42	61.44	19.97	5.21	0.49	0.63	0.59	1.38	0.85	0.13	6.82

0427

Normal Acid Brown Earth

Profile no. 29. A.B.E. Sample no's : W. 43, 44 & 45.

Location : Near the top of the Melmerby Scar Limestone feature about ¼ mile south of Knock Ore Gill.

Nat. Grid Reference : 693307.

Altitude: 1600ft. O.D.

Relief and aspect : A slope of 20° with a south westerly aspect.

Geological data : The soil is developed in a layer of superficial material overlying the Melmerby Scar Limestone.

Vegetation : Agrosto - Festucetum

Horizon : ins	
0 - 3 A	Very dark grey brown 10 YR 3/2), friable, stony clay loam; strong fine crumb; abundant live roots; moderate organic matter content; clear regular boundary.
3 - 10 (B)	Dark brown 7.5 YR 4/4), friable to firm, stony clay loam; strong medium crumb; frequent live roots; low organic matter content; clear regular boundary.
10 - 23 C	Dark brown (10 YR 4/3), very firm, stony clay; strong medium to coarse blocky; slight induration; occassional roots to 17" ; stones seem to be concentrated at the top and base of the horizon; sharp irregular boundary.

Profile no. 29 A.B.E.

Sample no.	Depth (ins)	p.H.	$CaCO_3$%	Free Fe_2O_3 %
W.43	0 - 3	4.9	0	2.2
W.44	5 - 8	5.9	0	2.6
W.45	12 - 16	5.8	0	1.9

	U.S.Sand	I.Sand	I.Silt	Clay	U.S. Silt %
W.43	35.9	46.1	16.9	29.2	34.9
W.44	31.5	42.5	19.9	37.6	30.9
W.45	12.5	20.8	18.8	60.4	27.1

	% B.S.	Extractable Ca	Mg	Na	K	L.O.I.%	%C	%N	C/N
W.43	23	1.0	0.34	0.49	0.41	15.47	2.37	n.d.	n.d.
W.44	29	0.9	0.17	0.64	0.22	7.87	1.34	n.d.	n.d.
W.45	37	5.6	1.53	0.47	0.34	7.66	1.28	n.d.	n.d.
		meq./100g.							

	Si	Al	Fe	Mg	Ca	Na	K	Tl	Mn	H_2O%
W.43	70.50	9.52	5.01	0.31	0.60	0.68	1.14	0.92	0.15	8.78
W.44	68.42	13.84	5.65	0.39	0.52	0.62	1.16	1.24	0.16	6.67
W.45	57.07	23.77	5.51	0.42	0.58	0.58	1.48	0.86	0.16	8.00

CHAPTER 22.

Peaty Gleys

The peaty gleys are probably the most extensive mineral soil sub-group, on the Reserve. They are found at almost all levels within the area but they are particularly associated with gradual slopes. They generally merge with blanket peat in one direction and often with peaty gleyed podzols in another. The boundary between peaty gleys and blanket peat is a purely arbitrary one and a gleyed soil is the most common sub-peat soil. The vegetation associated with the peaty gleys is a Juncetum squarrosi sub-alpinum or a Juncus facies of the Nardetum sub-alpinum (p. 59).

Although usually classified as ground water gleys the peaty gleys usually have surface water gleying and ground water gleying. They are gleyed at the surface because of the sponge effect of the surface mat of humus and they are gleyed at depth because of the high ground water table. The high ground water table would seem to be the controlling factor.

The peaty gleys are developed in a layer of superficial material overlying various rocks of the local Carboniferous succession.

The soils in question always have a surface mat of peaty, or mor, humus. The thickness of this mat varies greatly and merges with blanket peat. Plant remains are often easily recognisable in the peaty layer which is black in colour and very acid with p.H. values of 3.5 - 4.0. The boundary with the underlying mineral soil is generally sharp and level.

The surface horizon of the mineral soil is always gleyed to some extent and always contains abundant live roots. The structure of this horizon is always weak and quite often it is massive and structureless. Any structure which is present is usually weak, coarse blocky or prismatic. In detail the A horizon can vary a great deal. In some examples the horizon is a uniform

Plate 76. Gleying under blanket peat on Hard Ridge.
(The scale is 6 ins).

grey brown colour and the total iron contents seem to indicate that it is an eluvial horizon. This A_{2G} horizon is found in soils which are transitional to a peaty gleyed podzol. In other examples the A horizon is not uniformly coloured but has yellow or ochreous, clear to distinct mottles on a grey brown ground colour. In these A horizons the mottles are usually restricted to root channels and are generally small. Total iron determinations do not appear to indicate any removal of iron from these mottled A horizon but a redistribution within the horizon has visibly taken place. Vertical fractures are sometimes present in the A_G horizon and the faces on either side of these fractures are usually stained dark brown or black by organic materials.

The boundary between the A_G and the underlying soil is usually merging although level. In the peaty gleys with a uniformly coloured A_G the junction is rather sharper and is often marked by the incoming of distinct ochreous mottles. In profiles with mottles throughout it is extremely difficult to subdivide the lower soil although in many cases the mottles become more numerous below the A_G and cease to be restricted to root channels. The body colour of the soils also changes from a grey-brown or brown-yellow in the A_G to a yellow-brown in the B_G. The structure is always weak and the horizon is commonly massive.

The appearance of the sub-soil and also the B_G, is largely controlled by the level of the ground water table. Some profiles contained abundant large, distinct mottles to the base of the pit, i.e. to a depth of 3' 6". In other examples the mottles have become small, once again, and are restricted to the root channels. Where the water table is particularly high a uniformly coloured grey or blue-grey subsoil may be present. These blue-grey subsoils are usually found in hollows which are badly drained or where the superficial material, in which the soil is developed, rests upon shale. This type of sub-soil may also be

Plate 77. Peaty gley near Swindale Beck.

found near streams. Examples of freely drained subsoils are rare and virtually restricted to where the soil parent material rests on limestone and even then they are the exception.

In extreme cases, most commonly found under blanket peat, the mineral soil is a grey or blue grey colour throughout with no mottles. These profiles are most commonly found at the base of slopes which are close to streams. In both cases it is difficult to determine whether the whole of the gleying is due to a high water table or whether the gleying of the surface horizon is due to the presence of the peat mat. Where the superficial material forms a 'bluff' at the sides of streams the surface gleying must be due to the surface humus. In other cases one would have to determine the position of the ground water table throughout the year but in these cases the soils are best designated ground water gleys. Mentioning these particular soils helps to show that the peaty gleys found in the Moor House area are, in almost every case, an intergrade between a true surface water gley and a ground water gley. Only over limestone, and then only occassionally, is the subsoil freely drained and the only gleying present due to surface moisture: one might add that it is difficult to see why a peaty gleyed podzol is not developed in the soils with a freely drained subsoil. In one direction the peaty gleys grade into a ground water gley and in the other direction, i.e. with improved subsoil drainage, they merge with the peaty gleyed podzols.

From the above it can be seen that a great variation in profile can be found. By far the commonest horizon morphology of the peaty gleys is one with a grey brown A_G with small to medium, distinct ochreous mottles which are usually restricted to root channels. This is underlain by a yellow brown B_G with frequent large to medium distinct ochreous mottles, not restricted to root channels: a moderate, coarse prismatic structure may be present in this horizon. The C_G horizon is a yellow brown colour with frequent distinct medium ochreous or yellow mottles: the structure is very weak.

All the profiles are stony to very stony throughout. In mottled horizons ochreous staining is often found around stones in the soil. Ochreous areas were also often found to associated with sandy pockets within the soil- this effect was noted by Crampton (1963) in South Wales and he suggests that it is due to the greater air space available for oxidation. The texture of the parent material is variable but always contains a moderate to high content of fines.

The chemical properties of the peaty gleys from Moor House show them to be acid, leached soils. The very low pH of the peaty layer has been mentioned above (p.430) but the values found in the mineral soil are little higher. The A_G, has a pH of between 4.0 and 4.5 and this increases down the profile to between 5.5. and 6.0 : slightly higher values are obtained from the base of peaty gleys overlying limestone. The percentage base saturation is very low and usually below 10 and often below 5 in the A_G and B_G horizons. Higher values, up to 30, can be found in the C_G. The loss on ignition results show the very clear cut junction between the surface humus and the mineral soil. Values for the surface humus are commonly between 60 and 70% but they are rarely above 8% for the A_G and are usually between 3 and 4% for the lower soil.

Peaty Gley

Profile no : 30 P.G. Sample no's : W. 17 - 20.

Location : Fifty yards from the fell wall near the Ministry of Aviation access road.

Nat. Grid Reference : 696297

Altitude : 1400 ft. O.D.

Relief and aspect : A slope of 4^{o} facing west south west.

Geological data : A layer of superficial overlies the Basement Series of the Carboniferous.

Vegetation : Juncetum squarrosi sub-alpinum

Horizon: ins.	
L	Trace.
$5\frac{1}{2}$ - 5 F	Recognisable plant remains
5 - 0 H	Black, wet crumbly peat; sharp, regular boundary.
0 - 7 A_G	Grey brown (10 YR 5/2), slightly plastic, stony loam; weak, coarse blocky; frequent live roots; wet; low organic matter content; gradual regular boundary.
7 - 15 B_G	Dark grey brown (10 YR 4/2), plastic, stony loam; wet; massive; occassional live roots; frequent, medium faint to distinct dark brown (7.5 YR 4/4) mottles, mainly along root channels; merging regular boundary.
15 - 39+ C_G	Dark yellowish brown (10 YR 4/4), plastic, stony loam; wet; massive; occassional roots to 26"; massive; frequent medium, distinct, yellowish red (5 YR 4/8) mottles, not restricted to root channels.

Profile 30 P.G.

Sample no.	Depth (ins)	p H.	$CaCO_3$%
W.17	2 - 5	3.9	0
W.18	9 - 11	4.3	0
W.19	14 - 18	4.8	0
W.20	20 - 24	5.2	0

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
W.17	40.3	62.4	15.5	22.1	37.6
W.18	39.0	44.7	23.2	22.1	38.9
W.19	63.4	52.9	25.6	21.5	44.1
W.20	36.2	52.8	22.6	24.6	39.2

		Extractable							
	% B.S.	Ca	Mg	Na	K	L.O.I. %	%C	%N	C/N
W.17	11	0.19	0.10	0.33	0.09	6.68	1.31	0.19	6.89
W.18	9	0.13	0.08	0.30	0.07	3.97	0	0.25	-
W.19	13	0.14	0.08	0.33	0.08	3.44	0	0.26	-
W.20	16	0.16	0.10	0.31	0.09	3.07	0	0.21	-
		meq./100g.							

	Si	Al	Fe	Mg	Ca	Na	K	Ti	Mn	H_2O%
W.17	89.30	2.89	1.40	0.00	0.52	0.69	0.62	0.63	0.03	2.82
W.18	84.35	5.68	3.45	0.17	0.53	0.73	0.97	0.63	0.04	3.43
W.19	79.08	9.57	3.80	0.40	0.53	0.76	1.25	0.68	0.04	3.90
W.20	77.80	9.93	3.77	0.40	0.54	0.75	1.35	0.58	0.04	4.85

Peaty Gley

Profile no.	31 P.G.	Sample no's.	W. 49, 50 & 51.

Location : Three-quarters of a mile north of Knock Ore Gill.

Nat. Grid Reference : 695307

Altitude : 1700 ft. O.D.

Relief and aspect : A slope of 6^{o} with a south westerly aspect.

Geological data : The soil is developed in a layer of superficial material overlying

Vegetation : Juncetum squarrosi sub-alpinum.

Horizon : ins	
L	Trace
3½ - 3	Brown, wet, Juncus and Nardus leaves.
F	Black, greasy peaty humus.
H	
0 - 8 A_G	Dark grey brown (10 YR 4/2), firm but plastic, stony clay loam; weak, coarse blocky; frequent roots; low organic matter content; frequent medium, distinct, yellowish red (5 YR 4/6) mottles along root channels and frequent fine ones of the same colour elsewhere; merging regular boundary.
8 - 30 B_G	Dark grey (10 YR 4/1), very firm, stony clay loam; massive; occassional roots; low organic matter content; frequent, medium to large, distinct, yellowish red (5 YR 4/1) mottles; merging regular boundary.
30 - 40+ C_G	Dark grey (5 YR 4/1), very firm, stony clay loam; massive; frequent, medium, distinct, strong brown (7.5 YR 5/6) mottles, but restricted to root channels.

Profile no. 31. P.G.

Sample no.	Depth (ins).	p.H.	$CaCO_3$
W.49	2 - 6	4.1	0
W.50	10 - 14	4.5	0
W.51	22 - 26	5.6	0

	U.S.Sand	I.Sand	I.Silt	Clay	U.S.Silt %
W.49	39.9	54.1	12.5	33.4	27.1
W.50	26.1	43.0	26.4	30.6	43.3
W.51	38.5	54.9	8.2	36.9	24.6

	% B.C.	Extractable Ca	Mg	Na	K	L.O.I. %	%C	%N	C/N
W.49	16	0.29	0.09	0.38	0.10	5.27	0.64	n.d.	n.d.
W.50	23	0.29	0.04	0.38	0.13	4.61	0.64	n.d.	n.d.
W.51	28	0.26	0.04	0.31	0.11	3.95	0.33	n.d.	n.d.
		meg/100g.							

	Si	Al	Fe	Mg	Ca	Na	K	T	Mn	H_2O %
W.49	72.16	13.74	4.37	0.34	0.51	0.66	1.07	1.16	0.04	5.33
W.50	72.34	15.07	3.70	0.42	0.50	0.62	1.07	1.14	0.04	4.78
W.51	76.11	13.27	2.68	0.40	0.51	0.65	1.35	0.97	0.04	4.03

CHAPTER 23

Parent Materials

The parent materials of the escarpment have not been examined in great detail but tentative conclusions can be drawn from the results which have been obtained. The actual summits of Great and Little Dun Fell, Knock Fell and Cross Fell have been considered previously (p.318) and the soils there seem to have developed in a parent material derived from in situ weathering of the underlying sandstones. The same appears to be true of the area of humus iron podzols on Hard Hill. The brown ranker (p.412) developed on the Ordovician tuffs in Middle Tongue also appears to be a sedentary soil. The only other soils in which the transported element in the parent material is very low are protorendzinas forming on ledges on the limestone cliffs. The other soils would seem to be developed in a layer of transported material of varying thickness and with varying contributions from the bedrock.

The superficial material varies in texture but the clay and silt contents are always above 20% and 25% respectively. It is always stony and often very stony. Two types of rock dominate the stones present, they are sandstone and Whin Sill. Above the Whin Sill outcrop the stones are almost entirely sandstones except on, and immediately below, the feature due to the Great Limestone where limestone predominates. Below the Whin Sill outcrop boulders of this rock are always numerous. No foreign erratics were found on the escarpment during the present survey but Trotter (1929) reports one from 2200 ft. O.D. and Johnson (Johnson and Dunham 1963) one from 1875 ft. O.D. The sandstone boulders were obviously derived close at hand and the way the Whin Sill is present only below its outcrop, and then in large amounts, suggests very restricted downslope movement.

TABLE 23.

Comparison of total chemical analysis of a soil formed in superficial material over the Whin Sill with a Whin Sill analysis.

Sample no.	W.23	W.24	Whin Sill*
S_1O_2	51.3	51.1	50.24
Al_2O_3	17.2	16.3	15.4
Fe_2O_3+FeO	8.6	8.7	13.0
M_gO	2.0	2.1	3.47
Ca O	0.7	0.6	8.87
Na_2O	0.7	0.7	2.39
K_2O	0.7	0.7	1.35
$T1O_2$	8.2	9.0	2.40
MnO	0.1	0.1	0.18
H_2O	9.1	9.1	2.0
C	1.3	1.63	-

* Average of four samples from Upper Teesdale. Smythe (1930).

Total chemical analyses have given interesting results for soils developed over, or immediately below, the line of the Whin Sill but where it does not actually outcrop (Table 23). The analyses indicate higher than average iron, sodium and titanium contents and lower than average silica (Table 24). These trends are what would be expected in a parent material derived in situ from Whin Sill. The similarity of the analyses of the C horizon of these soils with an analysis of the Whin Sill give the same indications. It would seem that the layer of superficial material which blankets the Whin Sill in places has been largely derived in situ from the Whin Sill. This would make a large contribution of glacial drift very unlikely at this level, i.e. between 1800 and 2000 ft.

Clay mineral studies show a variation in the type of clay mineral which dominates the clay fraction: quartz is important in all the clay fractions. The superficial material which covers the slopes of Great and Little Dun Fell and blankets the summit ridge has a clay fraction dominated by kaolin. Between the Great Limestone and the Melmerby Scar Limestone, but excepting a belt covering the Whin Sill outcrop, illite is the dominant clay mineral. In material covering the Melmerby Scar Limestone and at the foot of the feature due to this limestone kaolin is dominant once again. Below this illite becomes important once more (Table 25).

In the case of the material on the summit ridge it is significant that the beds above the Great Limestone are moderately rich in kaolin, especially the mudstones. Downslope movement of this material or in situ weathering would explain the dominance of kaolin in the superficial cover. The clay minerals are only a guide when considered alone but they are a useful one. The flat topped section of the summit ridge, i.e. Knock Ridge, could be considered a promising site for the accumulation of aeolian material but the layer of superficial material which is found would seem to be too

[redacted]

TABLE 24.

TOTAL CHEMICAL ANALYSES OF THE C-HORIZONS OF VARIOUS SOILS ON THE ESCARPMENT.

Sample no.	Soil sub-group.	Altitude (ft.O.D).	S_1O_2	Al_2O_3	Fe_2O_3 + FeO	MgO	CaO	Na_2O	K_2O	TiO_2	MnO	H_2O	C	Locational Comments.
W.5	P.G.P.	2450	66.8	17.7	4.1	0.7	0.6	0.7	1.9	0.7	0.1	5.7	0.9	Knock Fell.
W.8	B.C.S.	2450	61.1	17.8	6.5	0.7	0.7	0.6	1.5	0.5	0.4	7.3	2.9	" "
W.11	B.C.S.	1450	66.9	16.9	5.0	0.2	0.7	0.6	1.1	0.9	0.1	6.0	1.8	Melmerby Scar Lst. feature.
W.16	A.B.E.	1425	63.4	20.4	5.2	0.6	0.6	0.6	1.8	0.8	0.1	6.0	0.6	"
W.20	P.G.	1400	77.8	9.9	3.8	0.4	0.5	0.7	1.4	0.6	0.0	4.8	0.0	Below Melmerby Scar Lst.
W.24	P.G.P.	1850	51.1	16.3	8.7	2.1	0.6	0.7	0.7	9.0	0.1	9.1	1.63	Over Whin Sill.
W.28	B.P.S.	1350	76.6	10.9	3.6	0.7	0.5	0.7	2.2	0.5	0.1	4.2	0.0	Slopes of Knock Ore Gill.
W.33	H.I.P.	2750	62.0	15.1	5.0	1.4	0.5	0.7	2.2	1.5	0.1	10.1	1.4	Summit of Great Dun Fell.
W.37	P.G.P.	1300	64.1	19.2	5.2	0.5	0.5	0.7	1.7	0.8	0.1	6.1	1.2	Slopes of Knock Ore Gill.
W.42	A.B.E.	1500	61.4	20.0	5.2	0.5	0.6	0.6	1.3	0.8	0.1	6.8	2.5	Near Sink Beck.
W.45	A.B.E.	1650	57.1	23.8	5.5	0.4	0.6	0.6	1.5	0.9	0.1	8.0	1.6	Top of Melmerby Scar Lst feature
W.48	B.R.	1200	59.2	18.8	6.0	0.7	0.5	1.6	1.9	1.0	0.3	7.5	2.5	Over Ordovician tuffs
W.51	P.G.	1800	76.1	13.3	2.7	0.4	0.5	0.6	1.3	1.0	0.0	4.0	0.0	
W.56	B.P.S.	1550	66.4	17.3	5.5	0.8	0.6	0.6	2.4	0.8	0.1	5.2	0.2	Slopes of Knock Ore Gill.

443

stony and the clay contents, 30-40% too high and the silt contents 30-40% too low for this to be considered a likely source.

If the area of the Melmerby Scar Limestone outcrop plus the area at the foot of the feature due to the limestone are considered the kaolin in the clay fraction could also be derived close at hand. A seat earth very rich in kaolin is found overlying the Melmerby Scar Limestone and the fact that the area where kaolin is dominant is immediately below this suggests the seat earth as a likely source. It must be admitted that the indications of this clay mineral have to be treated with care. They indicate that downslope movement has taken place but downslope movement of clay minerals on a steep slope is a predictable phenomenon and has been postulated earlier (p.401). The results being discussed here show this to be a very reasonable postulation. Movement of clay minerals can take place without movement of larger material and so the presence of this kaolin does not necessarily indicate that all the superficial layer has come from so close at hand.

The area between the Great Limestone and the Melmerby Scar Limestone where the clay fraction is dominated by illite could also have its superficial cover derived close at hand. Illite is the most important clay mineral in the shales of the local Lower Carboniferous succession.

Taken together the above results seem to indicate that the bulk of the superficial cover has been derived very close at hand. The bulk of it is not in situ as is evidenced by the sandstone and Whin Sill boulders which are found in the material overlying limestones. The movement of the material and the distribution of the clay minerals could be adequately explained by downslope movement with little or no contribution from drift. If this were the case then the material must have suffered intense mixing at some stage to explain the stony nature of a material otherwise so rich in fines. Whether colluvial movement alone is

TABLE 25.

Clay minerals of various soils from the escarpment.

Profile no. and soil sub-group.	Sample no.	Clay Minerals 14A	10A	7A	Locational comments.
17 P.G.P.	W.1		W	W	Knock Fell
	W.2		M	M	
	W.5		W	M	
23 R.	W.6	W		M	Knock Fell
25 B.C.S.	W.10			M	Melmerby Scar Lst.feature
	W.11			S	
27 A.B.E.	W.12			M	Melmerby Scar Lst.feature
	W.13		VW	S	
	W.14		W	M	
	W.15		W	M	
	W.16		W	M	
30 P.G.	W.17			W	Below Melmerby Scar Lst.
	W.18		M	W	
	W.19		M	M	
	W.20		M	W	
18 P.G.P.	W.21			W	Over Whin Sill.
	W.22		W	W	
	W.23		W		
	W.24		W		
21 B.P.S.	W.26		S		Slopes of Knock Ore Gill.
	W.27		S	VW	
	W.28		S		
16 H.I.P.	W.29		W	M	Summit of Great Dun Fell.
	W.30		VW	W	
	W.31		VW	W	
	W.32		VW	M	
	W.33		VW	S	
19 P.G.P.	W.34		S	S	Slopes of Knock Ore Gill.
	W.35		M	M	
	W.36		W	M	
	W.37		S	M	

Sample no.		Clay Minerals 14A	10A	7A	Locational comments
	40			M	
28 A.B.E.	41		VW	M	Near Sink
	42		VW	M	Beck
	43		VW	M	Top of
29 A.B.E.	44		W	M	Melmerby Scar
	45		VW	M	Lst. feature.
	46		W	VW	Over
26 B.R.	47		VW	W	Ordovician
	48			VW	tuffs
	49		VW	M	
31 P.G.	50		M	S	
	51		M	S	
	52		VW	W	
	53		M	W	Slopes of
22 B.P.S.	54		S	M	Knock Ore
	55		S	W	Gill
	56		S	W	

sufficient to produce this degree of mixing is a difficult problem but it is perhaps significant that the material on the slopes of Great Dun Fell, which is almost certainly colluvium, is well mixed with large stones in a matrix rich in fines. Even if the material has suffered intense mixing during downslope movement the bedrock must have undergone a prolonged period of weathering to produce the necessary mantle of unconsolidated material. The period of time involved and the type of weathering involved are open to question but one small indication can be obtained. It has been mentioned above that between the Great and Melmerby Scar Limestone illite is the dominant clay mineral except for a belt over the line of the Whin Sill outcrop and here the content of clay minerals, as revealed by X-ray studies, is very low. If weathering had taken place at high temperatures one would expect clay minerals to be produced from the pyroxenes and feldspars in the Whin Sill. The lack of any such clay minerals may indicate weathering at low temperatures.

The results considered above may be interpreted as indicating a colluvial origin for the material but other explanations must be considered. One may be observing large scale downslope movement which post-dates the deposition of a drift cover. This would produce further mixing and may increase the importance of locally derived material, although this would also dominate any drift. The results may also indicate that any ice on the slopes of the escarpment was clear ice and little if any foreign material was being introduced. Trotter (1929) thought that the ground above 2200 ft. O.D. was covered in ice similar to the highland ice of the Antartic : the present results may indicate a much lower bottom limit to this type of ice. Whether one is looking at reworked drift or colluvium it is certain that the parent materials of the escarpment are dominated by locally derived material which, in most cases, has been moved a short distance downslope.

As a parent material the layer of superficial material is chemically fairly uniform except for the belt over the Whin Sill outcrop (Table 24). The high silica content of the material almost certainly reflects the important contribution from the sandstones. The material is comparatively base poor and under the climatic conditions prevailing these bases will be released very slowly. This will increase the tendency for base poor, acid soils to develop. Although the texture of the material varies somewhat the content of silt and clay is always moderate and the variations in texture alone are unlikely to cause variations in the soils developed. As a result the superficial cover provides a relatively uniform parent material wherever it is thick enough to seal off the bedrock.

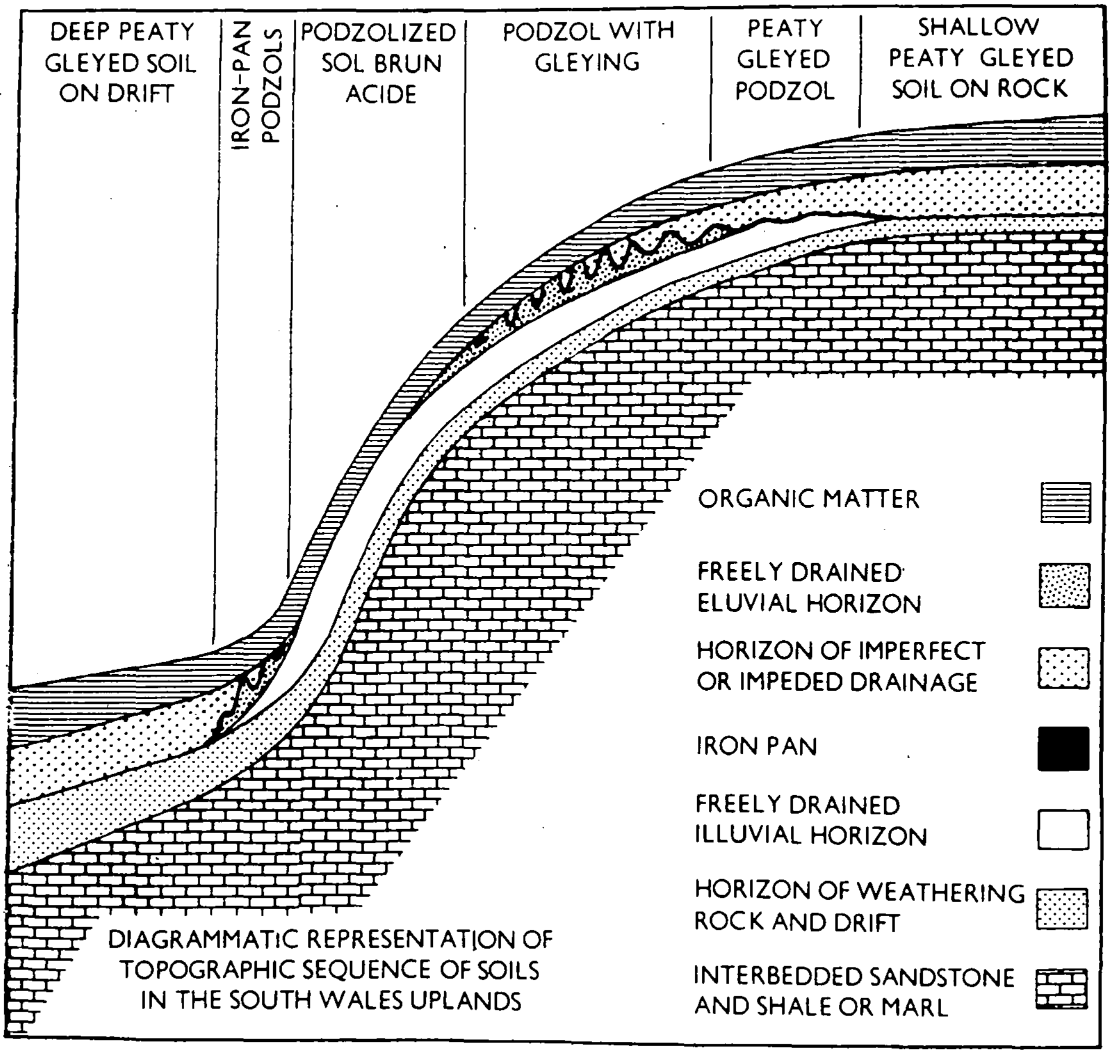
CHAPTER 24.

Distribution of the Soils of the Escarpment.

The distribution of the soils on the escarpment reflects the presence or absence of a cover of superficial material, and, when such a cover is present, its thickness and the angle of slope of the surface. As mentioned in the previous chapter the humus iron podzols are limited by the occurrence of the extremely sandy, acid parent material with no addition of transported material. The occurrence of the two phases of this sub-group is determined by topography, the deep phase being found on the level, stable sites and the shallow phase on more restricted, unstable sites. The brown ranker is also a sedentary soil with the bedrock still exerting a strong influence.

Other breaks in the mantle of superficial material are produced by outcrops of limestone, and to a lesser degree the Whin Sill and sandstones. The limestone cliffs formed by the Great Limestone at Green Castle and the Melmerby Scar Limestone north of Knock Ore Gill are bare limestone with skeletal rendzinas forming on ledges. The Whin Sill forms small cliffs in places and again skeletal soils are forming on ledges.

The limestone and the Whin Sill not only exert an influence on soil development when they give rise to an area completely free of a superficial cover, e.g. on limestone cliffs, but also when they cause a thinning of the superficial cover or cause a change of slope. As was seen in the previous chapter the superficial material is chemically reasonably constant and so within the area mantled by such a cover the parent material factor is constant. The soils developed will be dependent upon the other factors, unless the superficial layer is thinned sufficiently to allow the underlying bedrock to exert an influence. Of the remaining factors, the macro-climate and time can also be considered reasonably constant but



Diagrammatic representation of topographic sequence of soils in the South Wales uplands.

(After Crampton 1965)

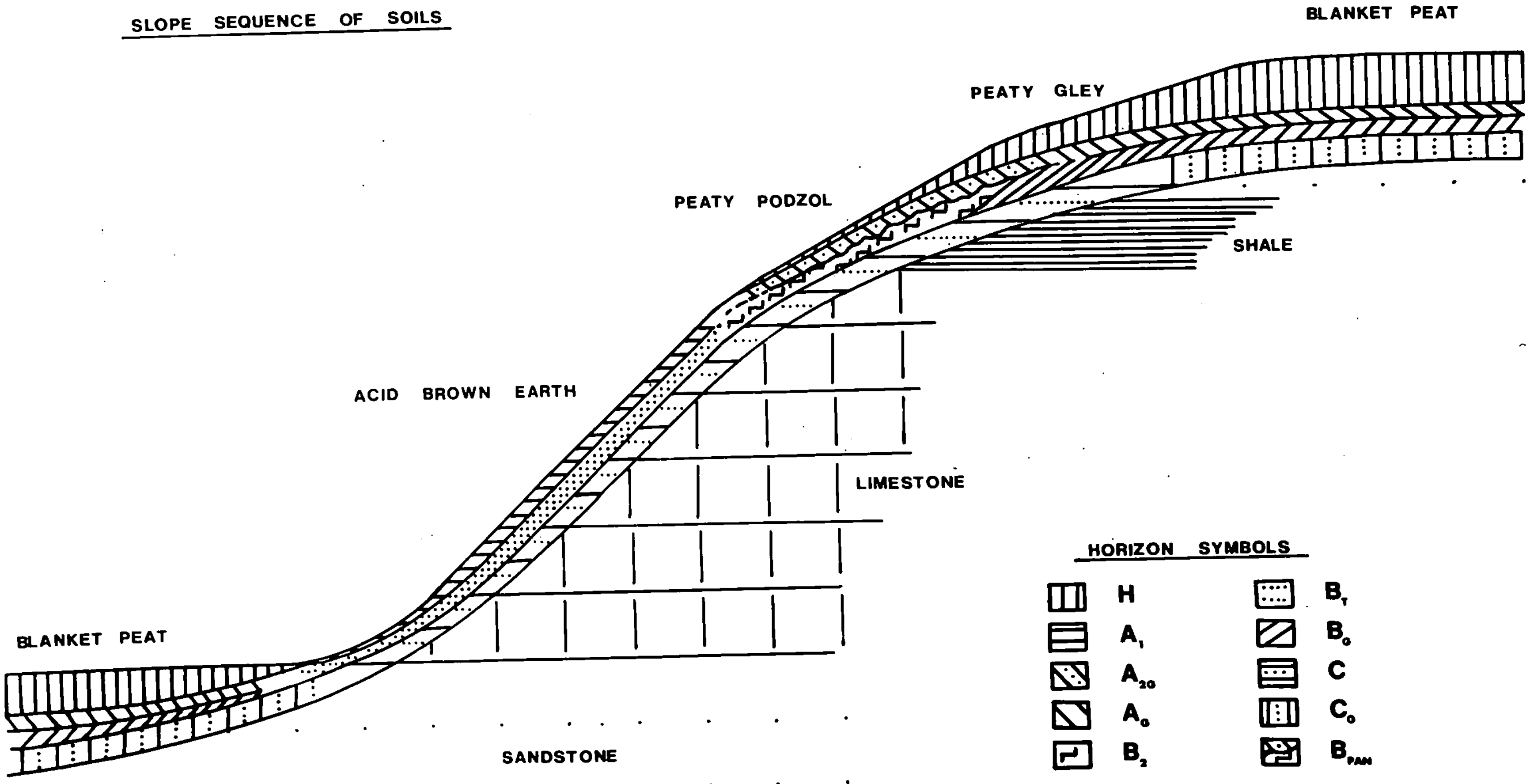
Fig. 41.

variations in vegetation, topography and management occur. The most important of these variables is topography, and the variations are due to the stepped topography produced by the local lower Carboniferous strata (p.32), plus the intrusive Whin Sill, and the steep sided valleys of the escarpment.

The stepped nature of the escarpment produces a variation in the angle of slope which produces a variation in soil drainage. This produces a drainage sequence of soils such as considered by Glentworth and Dion (1949) and Crampton (1965) (Fig.41). The flatter benches are covered in blanket peat with, usually, a zone of peaty gley at the downslope edge of the bench. This zone of peaty gley is probably free of peat because of instability due to the proximity of a break of slope. As slope increases a peaty gleyed podzol is produced and on the steeper slopes a brown podzolic soil or an acid brown earth (Fig 42). This succession is idealised and rarely complete. Changes in slope are usually rapid and hence cut out, or condense, some stages of the succession. Approaches to this succession are found over the features due to the Whin Sill and the smaller limestones and also on the slopes into the valleys of the escarpment. In the case of the limestone features the soil drainage is not only improved because of the increase in slope but also due to the permeable nature of the underlying limestone. The better drained members of the sequence are present on much gentler slopes when the slope is underlain by limestone than if sandstone or Whin Sill are present. On slopes not underlain by limestone peaty gleys are usually found on slopes of less than 7^{o}, peaty gleyed podzols on slopes of 7^{o} - 15^{o} and the acid brown earths on slopes of more than 20^{o}. Peaty gleys are often on sites found to be restricted and to be stable enough for blanket peat to exist.

Although any succession which is quoted must be a generalisation and unlikely to be found complete in any transect on

451



SLOPE SEQUENCE OF SOILS
BLANKET PEAT
PEATY GLEY
PEATY PODZOL
SHALE
ACID BROWN EARTH
LIMESTONE
BLANKET PEAT
SANDSTONE
HORIZON SYMBOLS
H
A1
A2G
AG
B2
BT
BG
C
CG
BPAN

FIG. 42

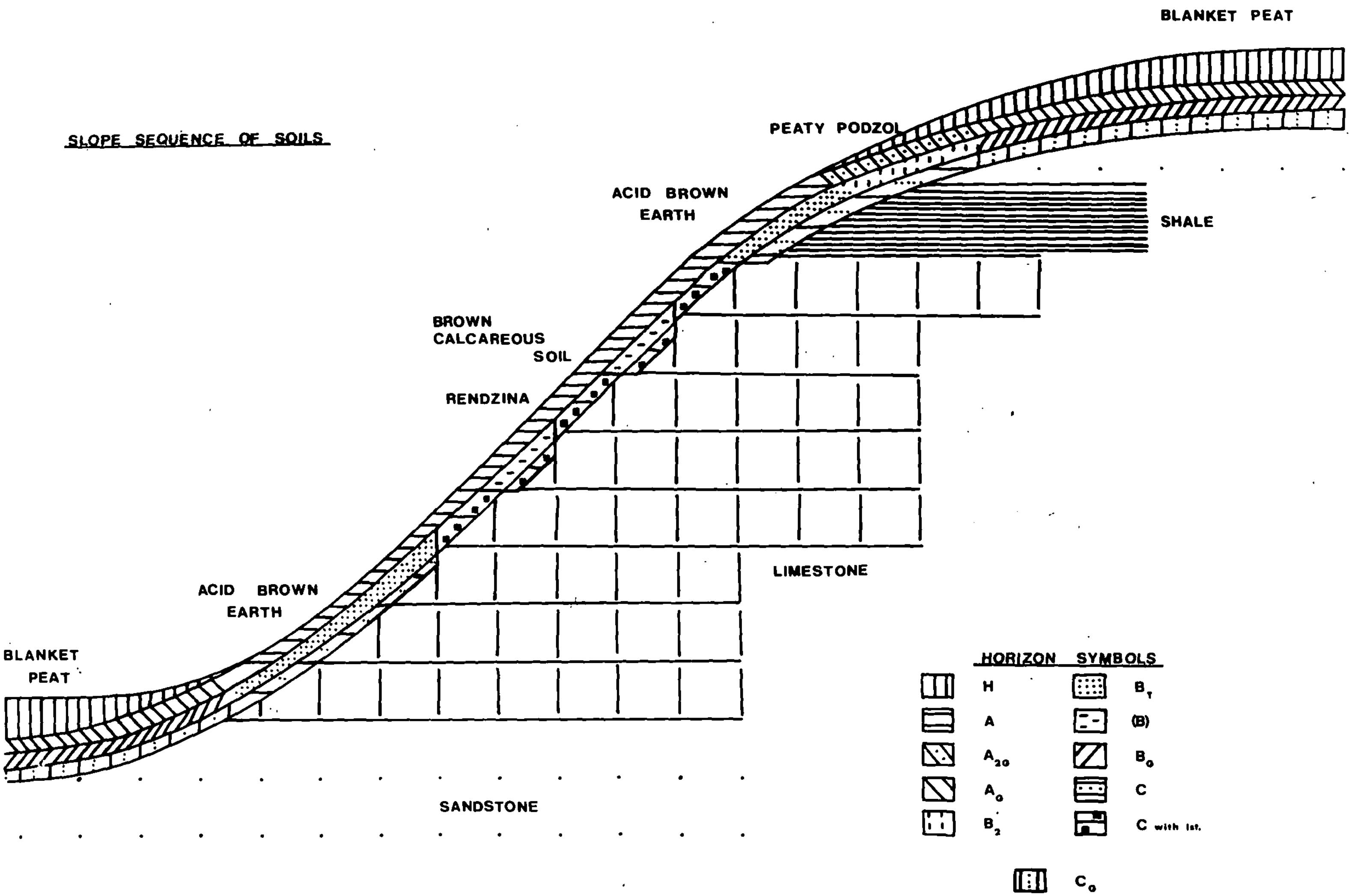

SLOPE SEQUENCE OF SOILS
BLANKET PEAT
PEATY PODZOL
ACID BROWN EARTH
SHALE
BROWN CALCAREOUS SOIL
RENDZINA
LIMESTONE
ACID BROWN EARTH
BLANKET PEAT
SANDSTONE
HORIZON SYMBOLS
H
A
A_{2G}
A_0
B_2
B_T
(B)
B_G
C
C with lst.
C_G

FIG. 43

the escarpment the different stages in a very gradual drainage sequence are found at various sites. As the various soil sub-groups were discussed the variations in morphology were pointed out; the variation is particularly marked in the peaty gleys and peaty gleyed podzols. These variations often fit into a continuing sequence. In the peaty gleys a progression is found from a completely gleyed blue-grey soil, through one with a uniformily gleyed zone overlain by a mottled zone, to one with mottles throughout the sub-soil and finally a relatively freely drained horizon at depth. These freer drained peaty gleys may show iron depletion in the A_{2G} and accumulation in the (B) and would be classified by some (e.g. Glentworth 1966) as podzolic gleys. They are obviously transitional to the peaty gleyed podzols. The peaty gleyed podzols also show a succession from a mottled, gleyed sub-soil to a freely drained sub-soil. The two sub-groups thus overlap to a considerable extent. Within the freely drained sub-groups, i.e. brown podzolic soils and acid brown earths, gleyed varieties are also found. Although the above soils can be placed in a drainage sequence it can be seen that the various sub-groups overlap and, in effect, give parallel sequences. This does not destroy the idea of a drainage sequence and the idea that, given a mantle of superficial material, the soils developed at a given site largely depends on the soil drainage conditions which in turn, reflects the slope.

In the case of the features due to the thicker limestones, especially the Great and the Melmerby Scar, the feature may be large enough to cause a thinning of the superficial cover. Because of this thinning the limestone is able to exert an influence on the material and calcareous soils are produced (Fig 43). This produces another type of succession. At the top and base of the feature an acid brown earth tends to be developed and on the face of the feature a complex of brown calcareous soils and rendzinas depending on the thickness of the superficial cover. In some places no marked thinning of the cover takes place over the limestone feature and then the limestones act to give better soil drainage but exerts no chemical influence on the soil.

On level areas of limestone the soils developed at a given spot are controlled by the depth of superficial cover which is resting on the limestone at that spot. Complexes similar to those discussed as limestone grassland sites east of the summit ridge are developed on these level sites. This kind of depth controlled complex is found on the level outcrop of the Great Limestone on the top of Green Castle and the northern end of Knock Fell. A depth control is present on the sloping sites as only when the thickness of superficial material is reduced on the scarps are calcareous soils found.

The limestones can, therefore, act in four ways; on flat limestone outcrops a sequence of soils is produced which is controlled by the depth of superficial material, but where the limestone forms a steep slope it can act to improve soil drainage only, to thin the superficial cover and give calcareous soils or to give limestone cliffs.

Within this very general framework one can have a great variation and hence a complex pattern of soils. The normal drainage sequence from blanket peat to a brown podzolic soil or acid brown earth may be interrupted at any stage by a limestone feature and associated calcareous soils. The fact that the benches between the limestone scarps have varying slopes causes a variation in the soils found on these benches but they are never steep enough to result in a better drained soil than a peaty gleyed podzol.

The inter-relationships of the soils present on the Reserve is indicated by the various sequences which have been discussed. The humus iron podzols are probably the stable soil on the very acid, sandy parent materials with which they are associated.

Whether this is a climatic climax is more doubtful and it is more likely to be a site climax, the parent material being extremely acid. The other sedentary soils, the brown rankers and the skeletal soils on the limestone and Whin Sill ledges are very immature and will evolved towards a site or climatic climax.

The other soils discussed are, for the most part, evolutionary stages. As discussed in chapter 14 the present writer is of the opinion that on level areas of limestone the shallower soil types i.e. rendzina, brown calcareous soils and acid brown earths, are stages in the evolution towards the climax type which would be some kind of podzol. Thus the depth sequence which we now see over limestone parallels the evolutionary sequence. If we consider the calcareous soils on the sloping sites associated with the limestone scarps a different situation may well exist. On the steeper slopes the inherent instability of the sites may well maintain the soil cover thin enough to enable the limestone to continue to exert an influence. In that case the calcareous soils may well be a site climax.

The acid brown earths and brown podzolic soils may also have a different status depending on the site. On level sites overlying limestone it is difficult to see them being maintained. It is far more likely that podzolization will become more intense as the superficial cover is thickened by addition of the insoluble residue from the limestone. On the steep valley sides the instability may be sufficient to offset leaching to some extent by continued intermixing of material. It is also unlikely that drainage could be impeded enough in the A_2 to produce a peaty gleyed podzol. The problem is whether or not the acid brown earths would evolve to a brown podzolic soil and this is probably dependent upon the micro-conditions. Thus the acid brown earths at the base of some of the limestone scarps may be maintained by slight flushing by lime rich waters from the limestone. Similar flushing must be present on some of the steep valley sides as bands of limestone are present in the valley sides.

The peaty gleys are almost certainly site climaxes on most sites where they occur and are very unlikely to evolve towards any other soil. The only likely direction of change of the peaty gleys is for the surface humus layer to increase and become blanket peat. This latter change could also take place on the peaty gleyed podzols on gentle slopes; on the steeper slopes the blanket peat will be unstable. One is left with the question of whether the climax over much of the area would be blanket peat and not a podzol. If the 55" suggested by Pearsall (1950) is really sufficient rainfall for blanket peat development then peat development will follow once the peat forming vegetation becomes established on a site. The distribution of peat would then be limited chiefly by slope. The ultimate question then is whether or not all the areas of mineral soil which now exist on the Reserve are on sites where some factor will prevent peat forming or reforming. With peat erosion proceeding so rapidly it is highly unlikely that peat will develop in areas now free of it but it may well be that on some of the level or gently sloping sites now occupied by a peaty gley, peaty gleyed podzol or humus iron podzol blanket peat is the true climatic climax and we are examining a series of site climaxes.

The peaty gleyed podzol, as we now see them, may also be an evolutionary stage. The podzolisation involved in these soils involves intense leaching of bases and iron, and sometimes manganese, but the intense chemical alteration of the A_2 does not seem to be far advanced. 'Lessivage' of clay minerals is also absent or insignificant but one would expect it to increase and produce a hard pan associated with normal podzols. Lessivage almost certainly causes a build up in fines in the B horizon of the other freely drained soils and this could affect soil evolution.

The comments made above have mainly applied to the areas of mineral soil without a cover of blanket peat. Examination of blanket peat areas appears to show that drainage conditions were also important in pre-peat soils now sealed below the blanket peat. Peaty gleyed podzols were only found below the blanket peat where the superficial material in which the soils are developed overlies limestone. In these cases the sites would be rather better drained because of the limestone and this would ensure vertical percolation in the soil. It should be stressed that peaty gleyed podzols are not always present below blanket peat overlying limestone.

Most of the above discussion has been referred to the escarpment but the underlying factors also apply to the dip slope. In the peat free areas of the dip slope the soils found depends on the presence or absence of a superficial cover. Given a superficial cover then the drainage conditions as, determined by the slope, become important. Limestones again cause variations when the superficial cover is thinned over them and calcareous soils are produced.

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APPENDIX A.

Definitions of terms used in profile descriptions.

A.1. Horizon nomenclature

The nomenclature used in the present work is based mainly on Kubiena (1953).

L - a superficial layer of undecomposed plant litter.

F - a superficial layer of partially decomposed litter, in which the plant remains are clearly recognisable.

H - a superficial layer of decomposed organic matter with few recognisable plant remains.

A_1 - the uppermost minderal layer, dark coloured, organic matter mixed with mineral matter.

A_2 - a layer immediately below the A_1 containing less organic matter, grey or grey brown in colour, rich in silica and having suffered the maximum loss of bases and sesquioxides. May show signs of gleying in which case the colour is dull grey or blue grey; the gleying is indicated by designating the horizon as A_{2G}.

A - mixed mineral and organic horizon, brown coloured with medium organic matter but no differentiation into A_1 and A_2.

B_{1H} - in podzolised soils the horizon showing the maximum deposition of humus.

B_{PAN} - in podzolised soils, a thin iron pan, usually about $\frac{1}{8}$ - $\frac{1}{4}$" thick. Maximum enrichment of sesquioxides; may be continuous or discontinuous.

B_2 - brighter than the A or C horizons; marked enrichment of free sesquioxides.

B_3 - not so bright as B_2, some enrichment of sesquioxides, nearer to the colour of the parent material.

B - horizon showing some enrichment of sesquioxides and/or humus but no differentiation into B_{1H}, B_{PAN}, B_2 etc.

B_t - horizon showing some addition of sesquioxides and also enrichment of clay grade material: B_{2t}, B_{3t}, etc. are also recognised.

(B_t) - horizon showing enrichment of clay grade material but no marked enrichment of sesquioxides.

(B) - horizon between the A and C horizons of soils where there is no clear depositional horizon.

(B) C
BC - transitional horizons between B or (B) and C but more closely allied to B or (B).

C (B)
CB - transitional horizons between B or (B) and C but more closely allied to C.

C - the parent material from which the solum has formed.

D - horizons below the soil profile the presence of which is significant in the behaviour of the soil.

Gleying in any of the above horizons is indicated by adding the suffix 'G', e.g. B_G , C_G.

The definitions of the terms used to describe structure, texture etc., are based on those used by the Scottish Soil Survey and outlined in "The Soils round Aberdeen, Iverurie and Fraserburgh" (Glentworth and Muir 1963); the following draws heavily upon the above memoir.

A_2. 2. Colour

Soil colours were described with reference to the Munsell Soil Color Charts (Munsell Color Co. Inc., 1954).

A.3. Texture

The texture of a soil depends on the relative proportions of the various size groups of primary particles. In particular it refers to the proportion of sand (particles 2 m.m. - 0.05 m.m), silt (0.05 m.m. - 0.002 m.m), and clay (less than 0.002 m m.) in that part of the soil which passes through a 2 m.m. sieve.

The textural class names are those established by the U.S.D.A. and were determined by plotting the percentages of sand, silt and clay on a triangular diagram. The particle sizes quoted above are those used by the U.S.D.A. and must be used when using the textural class names employed by the U.S.D.A.

An alternative scheme of definition of particle sizes is known as the International Scheme. In this scheme sand is defined as particles 2 m.m. - 0.02 m m., silt 0.02 m.m. - 0.002 m.m. and clay less than 0.002 m m. In the results values of both U.S.D.A. and International silt are quoted. It is also convention to subdivide the sand size grade into coarse sand (2.00 m.m. - 0.02 m.m) and fine sand (0.02 m.m. - 0.002 m.m. or 0.05 m.m. - 0.002 m.m.) and values for U.S.D.A. coarse and fine sand are quoted in most, but not all, textural results.

An assessment of soil texture was made by 'feel tests' in the field but the textural class names quoted in the profile descriptions are based on the mechanical analyses made in the laboratory.

A.4. Structure.

The following structural types were recognised :

(i) Platy - the vertical axis is much shorter than the two horizontal axes.

(ii) Prismatic - angular aggregates with the two horizontal dimensions much shorter than the vertical one.

(iii) Blocky - angular aggregates with the three dimensions of the order of magnitude.

(iv) Polyhedral - angular fragments with the three axes roughly equal but more irregular than the blocky structure. This type is equivalent to the "Subangular Blocky" of the Scottish Survey but was substituted so that there were not two types of blocky unit which may be confused.

(v) Crumb - porous, rounded or sub-angular aggregates with very irregular surfaces.

The size of the aggregates was also assessed as below:

Fine - less than 1 cm.

Medium- 1 or 2 cm.

Coarse- several cm.

(Equivalent to the 'class' of the Scottish Survey)

The 'strength' of the aggregates is also indicated depending on how well formed the units are and how resistant when disturbed :

Weak - not obvious in the undisturbed soil and not very distinct in disturbed soil.

Moderate - not obvious in undisturbed soil but distinct in disturbed soil.

Strong - obvious in undisturbed soil.

A.5 Consistence

This quality of the soil is expressed by the degree of cohesion or adhesion.

In wet conditions this is expressed as non-plastic, slightly plastic, plastic or very plastic :

in damp conditions as loose, friable, firm, or very firm :

and in dry conditions as loose, soft, hard, or very hard.

A.6 Induration

This refers to a handling property of the soil not affected by moisture.

Weakly indurated - not detected on digging, breaks easily in the hand.

Moderately indurated - detected on digging, breaks in the hand with moderate pressure.

Strongly indurated - causes difficulty on digging.

A. 7 Organic Matter

This was estimated from the loss on ignition of the soil after making allowance for the clay content.

High organic matter content		13% - 20%
Moderate		8% - 13%
Low	less than	8%

A.8 Stoniness

The percentage stone content of each sample was estimated and expressed as follows :

few stones,	less than 15% by volume
stony,	15 - 50% by volume
very stony,	greater than 50% by volume.

A.9 Mottling

The following terms were used to describe the pattern etc. of mottling in mottled horizons.

Abundance :

few	-	mottles less the 2% of surface
frequent	-	mottles 2-20% of surface
many	-	mottles more than 20% of surface

Size :

fine	-	less than 5 m.m.
medium	-	5 - 15 m.m.
coarse	-	greater than 15 m.m.

Contrast :

faint	-	hue and chroma of matrix and mottles closely related.
distinct	-	matrix and mottles vary 1-2 units in hue and several units in value and chroma.

prominent	-	matrix and mottles vary several units in hue, value and chroma.

A.10 Horizon boundaries.

The distinctness of the boundary between horizons is based on the width of the boundary as below :

Sharp	-	less than 1 inch
Clear	-	1 - 2½ inches
Gradual	-	2½ - 5 inches
Diffuse (Merging)	-	greater than 5 inches

Appendix B.

Analytical Methods.

B.1. Mechanical Analysis.

(a) Pretreatment.

Samples were quartered and two quarters crushed with a pestle and mortar before being sieved through a 2 m.m. sieve. The 2 m.m. fraction was again quartered and two 50 g samples taken. The 2 m.m. fraction was retained for pebble counts. The 2 m.m. samples were treated with 150 ml. of hydrogen peroxide overnight to remove organic matter. Any remaining hydrogen peroxide was boiled off the next morning and the samples were boiled down to about 1/5 their bulk. After cooling 100 ml N/10 HCl. were added to break down any carbonate cemented aggregates and the resultant suspension stood for approximately one hour. The suspension was next filtered and the residue subsequently washed with hot water before being transferred to a weighed evaporating dish. The samples were dried to constant weight at 105°C. After a final weighing 100 ml. calgon (B.S. 1377) were added and the suspension warmed for 15 minutes before being stirred for 30 minutes by high speed stirrer. The dispersed sample was transferred to a litre measuring cylinder and made up to the mark with distilled water.

(b) Analysis.

The analysis was carried out using a modification of the technique of Bouyoucos (1951). The cylinders containing the samples were stood in a constant temperature both at 20°C throughout the analysis so as to rule out temperature corrections. Readings were taken at 46 sec, 4 min. 48 sec and 5 hr.

The clay and silt were next removed by decantation, the samples oven dried and then the sand fraction sieved on an automatic siever, into the number of fractions required.

B.2. Organic carbon and loss on ignition.

A value for the organic carbon of the soil was obtained for most samples from the loss on ignition value obtained for that sample. Twenty samples were selected and the organic carbon was determined using the method of Walkley and Black (1934): the loss on ignition of the same samples was determined as below and from both sets of results a regression of loss on ignition against organic carbon was plotted. This regression was used to determine the organic carbon content of subsequent samples from the loss on ignition values obtained for them.

Loss on ignition was determined by igniting 5 grm. of the soil in a porcelain crucible for 16 hours at 375^{o}C and repeating for subsequent periods of 1 hour until constant weight.

B.3. pH.

10 g of the 2 m m. fraction soil were mixed in 25 ml. of distilled water. The resultant suspension was stood for 30 minutes and stirred periodically during this time. After this time the p H was measured using a p H meter.

B.4. Exchangeable cations.

Extraction was carried out by shaking 5 g of the less than 2 m m. fraction of the soil in 200 m l. of normal neutral ammonium acetate for two hours. After extraction the suspension was filtered and the analyses carried out on the filtrate.

Calcium, sodium and potassium were determined by flame photometry (Ure 1954) and magnesium by direct photometry (Scott and Ure 1958).

Cation exchange capacity was determined by leaching the soil with neutral ammonium acetate and then with IN ammonium chloride. The electrolyte was removed by washing with 99% isopropyl alcohol and the adsorbed ammonium determined by the acid-sodium chloride method (Chapman 1965).

B.5. Free iron.

The values for free iron were determined by Deb's method (Deb 1950) as outlined by Mackenzie (1954).

B.6. Total nitrogen.

Nitrogen was determined by a semi-micro-Kjeldahl digestion method (Markham 1942).

B.7. Calcium carbonate.

The calcium carbonate in the smaller than 2 m.m. fraction of the soil was determined by the rapid method outlined by Piper (1950). The calcium carbonate is removed by addition of a known quantity of hydrochloric acid and the acid then neutralised by addition of sodium hydroxide from a burette. The method is only approximate but the object was essentially to determine the presence or absence of free carbonate to aid in designation of soils as calcareous or brown earths.

B.9. X-ray Fluoresence Analyses.

(1) Pre-treatment of samples.

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The $\angle$ 2.0 m m. fraction of the soil was cone and quartered and the resultant aliquot crushed to a 20 micron powder in a Tema tungsten carbide disc mill. This powder was used for the subsequent analyses.

(ii) Trace element determinations.

The contents of Rb, Sr, Zr, Pb, Zn, Cu, Ni and Mn were determined on some of the samples which had been prepared as above. The powder was used direct and not briquetted (See iii) prior to analysis. The standards were prepared by the addition, or spiking, method (Ahrens and Taylor, 1961) with sample MB.13 being used as the dilutant. Standards containing +10, +50, +100, +300, +500, +750 and +1000 ppm. were used. The specpure chemicals used to prepare the standards were as follows:

Strontium	$SrCO_3$
Rubiduim	RbCl
Zirconium	$ZrOCl_2 . 8H_2O$.
Lead	$Pb(NO_3)_2$.
Copper	$CuSO_4 . 5H_2O$.
Manganese	Mn_3O_4.
Nickel	$NiSO_4 . 7H_2O$.

The analyses were carried out on a Phillips P.W. 1540 vacuum spectrograph and operating conditions are summarised below :

Tube and voltage	W target operated at 48KV 20 mA.							
Crystal	Topaz							
Collimator	480							
Path	Vacuum							
Counter	Scintillation							
Fixed time	3 x 64 sec.							
Element	Cu	Ni	Rb	Sr	Zn	Zr	W	Mn
Analysis line	K	K	K	K	K	K	L1	K
Peak $^{o}2\theta$	29.8	75.4	39.9	37.6	64.0	29.8	76.5	101.7
Background $^{o}2\theta$	28.5	74.2	39.7	36.6	63.00	28.5	78.0	99.5
	31.1		41.2	38.8	64.8	31.1		

The accuracy of the technique was checked by including recognised standards, e.g. G.1 and W.1. The reproducibility was monitored by repeating the analysis of one sample several times during the course of the analyses.

(iii) Major Element Analyses.

In recent years there have been great advances in the application of X-ray fluorescence analysis to major element analyses of silicates. These have enabled a great speeding up of total major element analyses and great use is made of this in geology. The present writer was interested in applying the technique to the total major element analysis of soils and investigated the possibilities during the present research.

As mentioned above the use of X-ray fluorescence techniques for silicate analysis allowed a great speeding up of the analyses. The initial analyses employed standards prepared by the addition technique (Ahrens and Taylor ibid) and only recent generations of X-ray machines have allowed the determination of light elements e.g. silica and aluminium. At a later date recognised standards were used to draw up a calibration curve, e.g. G.1., W.1., T.i., S.1., etc. Even more recently the application of computer analysis to the processing of the counts obtained from samples on the X-ray machine has enabled the most dramatic speed up. One of these computor techniques employing a self-consistent mass absorption (Holland and Brindley 1966) was employed in the present work and the experimental procedure is that outlined by these authors. A brief summary of some aspects of the procedure is given below.

The sample powder was prepared as in (i) and this was briquetted prior to the actual analyses. About 2 g. of powder were placed in a hydraulic ram, followed by approximately 1 g. of borax powder. (The borax acts as a backing and reduces the amount of sample needed to produce a briquette which can be easily handled) and compressed at 5 tons/in^2 for a minute. The resultant briquette was used in the analyses. A few samples contained insufficient clay and humic material to bind the briquette and in these cases the sample powder was mixed to a paste with 3-5 drops of a 2% solution of Mowiol (a chemically inert polyvinylalcohol cement transparent to x-rays) prior to compression.

It was decided to use the sample powder without further pretreatment in these early attempts to use the technique and in particular the samples were not ignited to removed organic matter. The operating conditions of the X-ray machine were as listed by Holland and Brindley (ibid) and fig.3 from their paper is reproduced here. The other conditions listed by these authors are also followed.

Two main problems were encountered. The first problem was met when providing standards with which the unknowns would be compared. The recognised rock standards were used, e.g. G.1., W.1., T.1., S.1., etc. but no well analysed soils with accepted results were available. To overcome this ten of the soils were analysed by conventional, wet chemical, techniques and the same samples were analysed by the chemical service of the Nature Conservancy at Merlewood. The intention was to use the rock standards as the primary standards and the soils as secondary standards. Secondly, the soils also contained variable amounts of carbon and water but in both cases they were too large to be omitted from any calculation of their composition. The organic carbon content was determined as indicated in B2, and the water as in B. 10.

When the counts were known for the samples and standards it became clear that the rock samples could not be used in processing of the unknowns. The soils were, therefore, the only standards used. The organic carbon and water contents of the unknowns were included in the computor but no mass adsorption corrections were made for them. In comparison with the rock standards the counts on the soil standards were depressed, relatively, for silica, but enhanced for the other elements. The organic matter may be responsible for these apparently anamalous counts. Despite the difficulties the author is convinced that meaningful results were obtained although they are, as yet, only usable internally and cannot be compared to results obtained by other methods.

Research into the method is continuing and in the next stage the samples are being ignited prior to briquetting and analysis. It was initially hoped that this could be avoided as it was felt that small amounts of some of the elements might be lost during the ignition. On the other hand it is very likely that it is the carbon which is causing the anomalous counts, when compared to the rock standards. The rock standards may be usable as the primary standards when one is dealing with ignited samples as these will then closely resemble rock powders. The use of the rock standards is much to be desired as the results for these standards are internationally recognised. The author is attempting to persuade various laboratories to analyse a number of soils by conventional means so that these will provide good secondary standards. Another disadvantage of using unignited samples is that water and organic carbon determinations have to be done on these and these are very time consuming and hence destroy one of the main reasons for using the method, i.e. its speed of analysis.

B.10. Chemical analysis for total contents.

These analyses followed the technique used in rapid analyses of silicate rocks as outlined by Shapiro and Brannock (1956) and Riley (1958).

B.11. Clay Mineral Studies.

a) Separation of the clay grade material.

The technique employed at the Macaulay Institute for Soil Research was used to separate off the clay grade material. The material examined was, therefore, 1.4 μ e.s.d.

b) X-ray examination.

The samples were examined on a Phillips 1540 diffractometer. Cavity mounts and smear mounts were both used on each sample. The operating conditions of the X-ray machine were standardised to enable rough comparisons to be made and they are listed below :

Tube and voltage Copper tube operated at 40 KV and 20 mA.
Slits $1/12^{\circ}$: 0.1° : $1/12^{\circ}$ ($0-5^{\circ}$), 1° : 0.1° : 1° ($5 - 70^{\circ}$).
Rate meter X 4
Time constant X 8

Multiplier X1

Channel width 4

Proportional counter 7/3 (1700 v).

Gonio meter speed 1^{o} per min.

Chart speed X 20.

The procedure outline by Warshaw and Roy (1961) was used in the systematic identification of the clay minerals and detailed spacings were compared with the A.S.T.M. Index for confirmation.

During the work some attempt was made to make semi-quantitative estimates of the contents of the various types of clay minerals. To this end standards were made up containing known quantities of standard clay minerals, e.g. Supreme kaolin, Fithian illite etc. Results were not considered satisfactory and so the very rough, strong, weak, very strong etc, notation was used.

B.12. <u>Heavy mineral studies.</u>

The international sand fraction, i.e. 0.02 - 0.2 m m. was used in this work and in general the material used in mechanical analyses was used when those analyses had been completed. The clay and silt were washed off using decantation and the coarse sand removed by sieving.

The heavy minerals were extracted from the fine sand using bromoform (S.G. 2.9). They were subsequently washed with acetone before being stood overnight in N/10 hydrochloric acid to remove iron coatings and stainings. Next morning they were filtered and washed with warm water and then acetone. Half the sample was usually mounted in Canada Balsam and prepared as a normal petrological microscope slide. The other half was examined in oil on a micrscope slide but not permanently mounted. The identification of the minerals followed the usual pattern in petrological microscope work.

At least 150 grains were examined, the restricted suits allowed this relatively small number to be dealt with, and the dominant minerals noted. Isolated occurrences were not noted. The indications of heavy mineral contents in Chapter 13 are not strictly quantitative but the restricted suites make the results meaningful.

Appendix C

A Critical Assessment of the Analytical Methods Employed and Discussion of the Results Obtained

C. 1. Mechanical analysis

Mechanical analysis determines the particle size distribution in a soil. The results were chiefly used to check field assessments of soil texture and to aid in the designation of horizons. The technique also provides information on the variation and origin of parent materials and, on the single profile scale, may indicate textural variations due to layered parent material and clay translocation.

Two methods are widely used for mechanical analysis. One is a hydrometer method developed by Bouyoucos (1951) and the other is the pipette method: the former was used throughout the present work. The pipette method is the more accurate but the hydrometer method provides adequate results for the routine uses mentioned above and for most parent material and pedogenic studies. It is a more rapid method than the pipette.

The results show a considerable range of textures due mainly to parent material variations. Glacial drift derived from the local Carboniferous rocks is the commonest parent material: east of the summit ridge the drift usually has a clay loam texture and this is reflected in a wide range of soil types. West of the ridge the drift varies from a loam to a clay loam but with no obvious pattern. The humus iron podzols have sandy textures inherited from the underlying sandstones and as such are very distinctive. A high silt content (up to 60%) is found in rendzinas and brown calcareous soils over the Four Fathom Limestone and this may be derived from the insoluble residue of that limestone (p. 200). The insoluble residue of other limestones may modify, or dominate, the parent material of the shallow calcareous soils found over them and a loamy texture usually results (p. 195).

Textural variations within profiles are also present. A layered parent material is present on the Moss Burn - Sheep Fold Site (p. 197) with a loam overlying a clay loam : the change of parent material was not determined from textural evidence alone. Some brown calcareous soils and acid brown earths show marked increases in clay content down the profile, e.g. in profile 29 ABE the increase is from 30% clay to 60%. This increase may be due to clay translocation (p. 400). Movement of silt, along with some clay, has taken place in the humus iron podzols and a plately structure is associated with the silt rich horizon (p.328) : similar phenomena in comparable soils in Scotland have been attributed to freeze-thaw activity and are said to date from the early Post-Glacial (p. 407).

C. 2. <u>Loss on ignition and organic carbon</u>

Loss on ignition is a guide to the amount of organic matter in a sample. Weight losses resulting from ignition include loss of water from clay minerals, losses due to ignition of carbon and, in calcareous soils, the loss of carbon dioxide due to the breakdown of calcium carbonate. The latter is very slight at 375°C, the ignition temperature used here (p. 482), and, as these soils contain little calcium carbonate, the contribution from this source must be negligible. Allowance for the loss of water from clay minerals is commonly made by subtracting 10% from the loss on ignition value.

A further indication of the content of organic matter is given by the organic carbon value. The carbon content is also used in the determination of the carbon : nitrogen ratio.

Calculation of organic carbon from the loss on ignition saves a great deal of time but the errors inherent in the loss on ignition technique will be present in this method. As stated above, the error due to breakdown of carbonates will be minimal. Ignition at 375°C instead of a higher temperature also reduces the loss of structural water from clay minerals : the greatest part of this loss takes place between 450 and 600°C. A further error will arise from the burning off of elemental carbon, e.g. coal or charcoal, present in the soil. The errors present in the Walkley and Black method, e.g. variable and incomplete recovery of carbon, and oxidation of chlorides and higher oxides of manganese, are also carried through into the calculation and are difficult to distinguish from those inherent in this technique.

Despite the possible sources of error this method was used because of the time saved and as the results were for routine work. Evidence that anomalous results were obtained is given by samples which gave a nitrogen value but no carbon e.g. W.34, p. 381. It is clear that where exact values for organic carbon are required a more accurate method, preferably a wet or dry-combustion, should be used.

In the mineral horizons the highest loss on ignition values (15-25%) are encountered in the rendzinas and brown rankers. The brown ranker shows a marked decrease in the C horizon whereas the value remains almost constant into the C horizon of the rendzinas. Brown calcareous soils the surface horizons give losses of between 10 and 15% and also show little variation with depth. Rather more marked decreases down the profile are characteristic of the acid brown earths and brown podzolic soils and these soils also show lower loss on ignition values in general with 5 to 10% being usual : profile 29 ABE gave an unusually high value of 15.47%. The mineral horizons of the peaty gleys and peaty podzols give very variable results of between 2 and 14% loss on ignition but most values lie between 3 and 8%.

In the humus iron podzols the humic B horizon is sometimes reflected by an increase in value relative to the overlying and underlying horizons. No such increase was detected in profile 16 HIP although this soil has a visibly distinct B_H horizon : this may be due to the nature of the humic material which forms a coating on grains and which may represent only a very slight carbon content. Two peaty gleyed podzols show an increase in loss on ignition with depth. In profile 13 PGP the increase is gradual whereas in 14 PGP it is restricted to a dark coloured, clay rich band at the soil/limestone interface. Both increases are paralleled by increases in nitrogen content and probably represent increases in organic matter, which may be due to translocation of organic matter.

C. 3. <u>Soil reaction</u>

The determination of soil pH electrometrically is now a standard procedure. In practice the pH of a soil/water suspension is measured and in such a suspension the apparent pH varies with the amount of water; for this reason the soil : water ratio used is usually quoted. The 1:2.5 ratio used was adopted by the Soil Reaction Committee of the International Society of Soil Science in 1930. The apparent soil pH may also show periodic variation with the time of year and the weather. The samples analysed here were all collected at similar times of the year to reduce these variations to a minimum.

Some laboratories carry out pH determinations in an M/100 calcium chloride solution as suggested by Schofield and Taylor (1955). This is said to more nearly represent the soil solution under actual field conditions and reduce the other errors mentioned above. The results obtained in the calcium chloride solution are usually 0.5 - 1.0 units lower than in water.

The following scale is used in discussing the results :

	pH (in water)
Strongly acid	<4.5
Moderately acid	4.5 - 5.5
Slightly acid	5.5 - 6.5
Neutral	6.5 - 7.5

The highest pH values are associated with the calcareous soils : the rendzinas are, in general, neutral and the brown calcareous soils have a neutral subsoil although the surface horizon may be slightly acid. The non-calcareous soils show varying degrees of acidity but become less acid with depth. In the acid brown earths moderately acid surface horizons overlie slightly acid subsoil although the humic surface layer may sometimes be strongly acid. Similar acidities are associated with the brown podzolic soils but the tendency for the surface layer to be strongly acid is more marked. The peaty gleys, peaty gleyed podzols and humus iron podzols are strongly acid although some become moderately acid with increasing depth. The increase in pH with depth is most marked, in all the non-calcareous soils, where they are found over limestone.

C. 4. Nitrogen

Nitrogen is an essential element for plant growth. It is present in the soil in inorganic and organic forms but only the inorganic fraction is available for uptake by plants. The amount in inorganic forms changes rapidly and consequently the most commonly quoted nitrogen analyses are total nitrogen, as these are much less liable to fluctuation. The Kjeldahl method for the determination of total nitrogen has gained wide use and its precision is well documented (Bremner, 1960).

Nitrogen contents vary from 2.59% to 0.03% and, in the mineral horizons, the highest contents are found in the surface horizons of the calcareous soils and the acid brown earths. Almost all the soils show a gradual decrease in content with depth but two peaty gleyed podzols show an increase at depth. As mentioned previously (p. 494) this parallels an increase in carbon content and is probably a result of translocation of organic matter.

The carbon : nitrogen ratio of a soil gives an indication of the degree of humification of the organic matter. Low C : N ratios are associated with mull type humus whereas higher values are typical of moder or mor humus. The surprising thing about the results is that they are uniformly low with no distinct trend. Field examination shows the rendzinas and brown calcareous soils to have a mull humus, and the low C : N ratio between 3 and 9 for the rendzinas and 4 and 15 for the brown calcareous soils, support these observations. Field observations indicated that most of the acid brown earths and brown podzolic soils had a moder humus but the C : N ratios are low, ranging from 3 to 10, indicating well decomposed residues. The ratios are similar for the high level and normal acid brown earths whereas field observations indicated a moder humus in the former and mull in the latter. Low values, 7.8 and 14.1 respectively, are also associated with the surface horizon of the humus iron podzols while field observations suggested, a mor humus. As a result the humus is being studied in greater detail to follow up these apparent anomalies.

Most of the peaty gleyed podzols and peaty gleys gave higher values which would indicate decomposed humus, but only the mineral horizons are quoted. An unusual trend in some is an increase in C : N values down the profile.

C. 5. <u>Exchangeable cations and base saturation</u>

Exchangeable cation analysis attempts to assess the amount of various cations available for uptake by plants. The method used determines the quantity of these ions free to exchange with cations of a salt solution added to the soil. As the proportion extracted varies with reagent the results have a purely conventional significance and are only directly comparable with others determined using the same exchange solution.

Despite this they allow some comparison between soils and are the most commonly used index of availability of these cations.

The cations usually determined are calcium, magnesium, potassium and sodium. The first three are essential elements for plant growth and calcium also helps maintain a particular acidity level in the soil. Sodium, although not essential to plant growth, can partially substitute for potassium in some plants but large amounts of the element depress growth.

The exchange solution also dissolves water soluble forms of the cations present. In non-saline soils soluble sodium and potassium are negligible but free carbonates of magnesium and calcium may cause overestimates of these ions. The calcareous soils examined here contain very small amounts of free carbonate which is unlikely to significantly affect the results.

Neutral ammonium acetate is one of the more widely used exchange solutions, thus making the results comparable with those of a larger number of other workers. Exchange was carried out by shaking the sample with ammonium acetate (p. 482) and after shaking the solution was filtered off. This contrasts with the procedure in some laboratories where the ions are extracted by leaching. Shaking tends to be quicker and simpler, and also allows batches of samples to be handled more easily. The results from the two methods appear to be comparable.

The spectrographic techniques employed in the determination of the quantities of the individual cations present are widely used and as such well tried. The results obtained from them are, therefore, generally accepted.

The following scale (after Metson, 1956) is used in discussing the exchangeable cation results :

	Ca	Mg	K	Na (m.e./100g.)
Very high	> 20	> 8	> 1.2	> 2.0
High	10-20	3-8	0.8-1.2	0.7-2.0
Moderate	5-10	1-3	0.5-0.8	0.3-0.7
Low	2-5	0.3-1	0.3-0.5	0.1-0.3
Very Low	< 2	< 0.3	< 0.3	< 0.1

Calcium is the dominant exchangeable cation in most of the soils examined but it also shows the greatest variation.

The highest calcium values are found in the calcareous soils. The rendzinas commonly give contents in the high range as do the lower horizons of the brown calcareous soils : the surface of the brown calcareous soils shows the effect of leaching with the calcium values dropping as low as 1.17 me./100g. (Profile 11 BCS). The non-calcareous soils give lower values with the acid brown earths and brown podzolic soils usually having low contents and the peaty gleyed podzols, peaty gleys and iron humus podzols very low. Where these soils rest on limestone the exchangeable calcium increases markedly with depth, e.g. profile 14 PGP gives very low values for the A_2 and B horizons but high values for the C.

The exchangeable magnesium values range from very low to moderate with the actual range being from 3.02-0.0 m.e./100 gm. The calcareous soils tend to show the highest values and are generally in the moderate or low range : no clear distribution pattern is discernable within the profiles but this may be a reflection of the shallow nature of these soils. The acid brown earths usually have values in the low range but occasional horizons may be in the moderate or the very low. Within the profiles the distribution pattern of exchangeable magnesium varies but there is a tendency for it to increase with depth in the profiles over limestone. The other sub-groups examined generally have values in the very low range with no distinct trends within the profiles except for the brown ranker which shows a marked decrease with depth. One of the brown podzolic soils quoted falls into the moderate range and one in the very low so that it is impossible to generalise about this sub-group on the basis of these profiles.

Exchangeable sodium values range from high to very low : in actual values, from 0.75-0.01 m.e./100g. There is no clear correlation of the values with soil sub-group but the calcareous soils almost always have values in the moderate range. The other sub-groups show a variation from profile to profile thus two acid brown earth profiles, 5 ABE and 6 ABE, are in the very low and low range respectively while the other three profiles of this sub-group have moderate values. Similarly the peaty gleyed podzols range from moderate to very low, the iron humus podzols from high to very low and the peaty gleys from moderate to very low. An interesting feature about the two peaty gleys with moderate values (30 PG and 31 PG) is that in both cases sodium is the dominant cation in all horizons : these are the only soils where a cation other than calcium dominates all horizons.

Although the exchangeable potassium values range from very low to high the distinctive feature about them is the uniform very low values with anything above this being unusual. The high value (0.84 m.e./100g.) is found in the surface horizon of the brown ranker and this soil shows a decline in content with depth. It is rather surprising that the values are so low as the local glacial drift, the most widespread parent material, contains an illite dominated clay fraction. Within the very low range the highest values are associated with the calcareous soils, the acid brown earths and the brown podzolic soils but there is no clear distinction between these sub-groups : usual values are between 0.1 and 0.4 m.e./100g. The peaty gleyed podzols, iron humus podzols and peaty gleys generally give values less than 0.1 m.e./100g. In those soils showing a variation in exchangeable potassium down the profile the trend is normally a decrease in values with increasing depth.

C. 6. Percentage base saturation

The percentage base saturation is a guide to the acidity of a soil and also the degree of leaching which the soil has undergone. It is here considered as the percentage of the cation-exchange capacity of a soil which is occupied by the four exchangeable cations discussed above. The cation-exchange capacity is the sum of the exchangeable cations of a soil but the values obtained will depend upon the exchange solutions used. Because of this it is important to state the method used and direct comparison should only be attempted with other results obtained by the same method. The results are best used internally, as in the present study, and only taken as an order of magnitude when comparing them with other work.

A variety of methods are available but the most commonly used are those in which the exchangeable cations are replaced by an acetate and the amount of replacing ion used determined by some means. Ammonium acetate is probably the most commonly used extractant but the author of the sodium acetate method gave more reproduceable results and as a result it was adopted. The decision may have been different had it been decided to do cation exchange capacity prior to carrying out the exchangeable cation analyses. In this case the samples would have been leached when doing the exchangeable cations and the exchange capacity determined on the same sample.

The percentage base saturation is highest in the calcareous soils with the rendzinas varying from 60 to 100 and the brown calcareous soils from 31 to 90 : it is a little surprising that the lower values are found in these calcareous soils. An increase with depth is found in both sub-groups and the relatively low values in the surface horizons of the brown calcareous soils are evidence of the strong leaching prevailing. Lower values are found in the other sub-groups and reflect the dominant role of leaching and/or podzolisation : thus the lowest values are found in the podzols (Peaty gleyed podzols 3 to 40 but usually between 5 and 15, and humus iron podzols between 5 and 15). The peaty gleys also have relatively low values ranging from 9 to 40 but being concentrated between 10 and 25. Acid brown earths and brown podzolic soils usually give intermediate results but are very variable. The former show a range from 6 to 71 but are generally between 20 and 40 and the latter from 8 to 36. Most soils show an increase in values with increasing depth and this is most marked in those soils overlying limestone bedrock.

C. 7. Total chemical analysis

Total analyses give the maximum content of the plant nutrients in the soil and can indicate a likely excess of a toxic element. In pedogenesis studies redistribution of various elements within the profile can be examined using total chemical analysis : it is best if these analyses are related to some assumed immobile element, e.g. zirconium. Differing parent materials vary in their chemical composition and total analyses could be of use in distinguishing them and assessing the contribution of the underlying bedrock.

In carrying out the total chemical analyses in the present work it was hoped to develop a rapid routine method using X-ray fluorescence techniques and then eventually to apply it to total analysis of whole soil samples and of fractions of the soil. In major element analysis by X-ray fluorescence techniques two chief systems are used. One briquettes the sample and standard powders while the other fuses them with a flux to produce a glass 'bead' which is used for the analysis. The former method was used as the geology department in Durham, where the present work was carried out, had developed it to the stage where it was being used as a routine method in rock analyses with a high degree of precision and accuracy. The merits of the fusion technique are now being further examined as the method is usually thought of as the more accurate.

The question of standards is a crucial one and was the stumbling block in the present work. Ideally many more standards are needed and they need to be analysed in several laboratories or many times in the available laboratories. This difficulty over standards may mean that samples have to be pre-ignited in future work thus enabling standard rocks to be used, or, alternatively, artificial standards with the fusion technique. Despite the problems encountered duplicate samples and repeat analyses of samples both indicated that results were reproduceable. It appeared, therefore, that the results could be used to compare samples. Comparison with results from other techniques must be tentative as it is difficult to check the accuracy of these analyses; when used in this way the results are best taken as guides.

The results obtained indicate the low total contents of the bases sodium, potassium, calcium and magnesium. Calcium contents range from 0.05% to 1.72% with the lowest values being found in two peaty gleyed podzols. The higher values are associated with the calcareous soils. The highest magnesium values (6.19 and 6.03%) are associated with a rendzina, profile 1R, and may reflect the high chlorite content of this soil. Apart from these two values the magnesium contents range from 0.03 to 2.2% with most values falling between 1 and 2%. The very low values are associated with the humus iron podzol developed over the Quarry Hazle Sandstone (Profile 15 HIP). Relatively high values, 2.0-2.2%, are found in soil containing many Whin Sill boulders. Sodium contents show a fairly limited range, 0.02 to 1.62%, and apart from one profile the highest value is 0.84%. The high values, 1.33 to 1.62%, are found in the brown ranker former over

Ordovician tuffs (Profile 26 BR). Once again, the very low values are associated with the humus iron podzol developed over the Quarry Hazle Sandstone. Most of the potassium contents fall between 1 and 2% but the range is from 0.62 to 4.47%. The high value is found in one horizon of an acid brown earth (5 ABE) which has a very high clay content (62%) and the clay fraction is dominated by illite : the high potassium undoubtably reflects this high illite content.

Most of the extreme contents of bases reflect a variation in parent material. The peaty podzol (18 PGP) containing many Whin Sill boulders and with fairly high magnesium values also has low silica values, relatively high iron and high titanium values. Comparison of the C horizon analysis with analyses of the Whin Sill (p.442) confirm a Whin Sill dominated parent material. The low sodium, magnesium and calcium values of the humus iron podzol over the Quarry Hazle Sandstone have been mentioned : the soil also has low manganese ($<$ 0.1%) and aluminium (0.8-5.6%) contents. These results are as would be expected from a soil derived from a relatively pure sandstone. The brown ranker (26 BR) was also shown to have a different total chemical composition to most of the soils and comparison with an analysis of the underlying tuff showed that it was almost certainly sedentary (p. 413).

The total iron values show the movement of iron in the podzols, e.g. profile PGP has 0.3% in the A_2 and 4.2% in the B. Total aluminium content reflects the clay increase down the profile of some acid brown earths, e.g. profile 29ABE it increases from 9.5 to 23.8%.

Total analyses were also useful in helping to show that the red colouration of some shallow soils over limestone was not an indication of maturity and that the iron was not derived from the underlying limestone as suggested by Johnson (1963). Soils of various colours and depths over the same limestone were shown to have similar iron contents. (p. 215).

C. 8. Trace elements

The trace element contents quoted in the present work indicate trace element levels for use in botanical studies but they were also carried out to help identify sedentary soils over limestone as opposed to those formed in drift. Strontium may be expected to be high in sedentary soils over limestone whereas rubidium and zirconium should be highest in the drift (p. 181 and 194).

The technique used for the determination of the trace elements, X-ray fluorescence, is a well tried one for this kind of analysis. The method of preparation of the standards, by spiking, is used in many laboratories and with it the technique has been developed to a high degree of precision and accuracy. Standards prepared in this way have the great advantage that the matrix effect in standard and sample is very similar.

The results obtained proved inconclusive from the point of view of the parent material investigations. In the soils over the Scar Limestone lower zirconium values (240-280 ppm.) are found in the rendzinas than in the peaty gleyed podzols (470-650 ppm.) and this would seem to support a contrasting parent material with the rendzinas being sedentary. No significant variation in strontium content was apparent, the range being from 230-500 ppm., and rubidium was higher, 210 ppm, in the rendzina than in the podzol (75-110 ppm.) which is contrary to what would be expected if the rendzina were a sedentary soil. Lead and zinc were higher in the rendzina (750 and 390 ppm. respectively) than in the podzol (175-580 ppm. lead and 0-410 ppm. zinc), but these elements may be mobilised and removed from the latter during podzolisation. Over the Tyne Bottom Limestone a higher strontium content was found in a rendzina (560-810 ppm.) than in a brown calcareous soil (240-460 ppm.) and an acid brown earth (230-315 ppm.) but no significant difference was found in zirconium and rubidium contents. The range of contents of zirconium and rubidium were 140-270 ppm. and 70-140 ppm. respectively. The interesting feature of these results, which were from soils from the Rough Sike Limestone grassland (p. 126), is the extremely high lead and zinc contents : lead varied from 1300-3900 ppm. and zinc from 1200 to 2900 ppm. These contents obviously reflect the veining in the limestone detected when a short trench was dug on the Rough Sike site.

C. 9. Clay Mineralogy

The clay minerals in a soil may be inherited from the soil parent material or may be formed within the soil profile by chemical weathering. It is unlikely that synthesis of new clay minerals is an important factor under the climatic conditions prevailing in the northern Pennines at the present day but some synthesis may have taken place under past, though relatively recent, climatic regimes. Despite this it was assumed that the clay mineral assemblage is predominantly inherited from the parent materials.

The method of separation of the clay fraction for analysis, by sedimenting out the sand and silt fraction, is simple but reliable. The actual procedures used in the identification of the 'species' of clay minerals present in the clay fraction vary from laboratory to laboratory but the scheme developed by Warshaw and Roy (1961) is one of the more widely used. It employs a combination of the techniques for clay identification, e.g. heating, treatment with glycol. The analyses were qualitative but as conclusions concerning the origin of the parent materials were based on a number of lines of evidence they were useful.

The glacial drift which blankets large areas east of the summit ridge has a clay fraction dominated by illite. This is almost certainly derived from the Carboniferous shales incorporated into the drift as they contain large quantities of this clay mineral. Soils derived from this drift inherit the illite dominated clay fraction and it is unlikely that soils with a clay fraction not dominated by it were derived from the drift. Calcareous soils over the Scar Limestone have a clay fraction dominated by kaolin which is almost certainly inherited from the insoluble residue of that limestone as this was shown to contain kaolin. In contrast the calcareous soils over the Tyne Bottom Limestone seem to have inherited a chlorite dominated clay fraction from the residue of that limestone.

In the humus iron podzols found on Great Dun Fell kaolin is the dominant clay mineral and this is true of other soils on the summit ridge. This kaolin is derived from the Namurian strata which form the summits and indicates that the soils are sedentary or, if they are transported, that the parent material has been derived from close at hand. On the western escarpment drift with an illite rich clay fraction would seem to be the dominant parent material and is reflected in a wide range of soil types. At the base of the escarpment soils with a kaolin rich clay fraction occur once again. It is possible that this is derived from a seat earth, composed almost entirely of kaolin, which outcrops above the Melmerby Scar Limestone, i.e. a short distance upslope of the kaolin rich soils.

C. 10. <u>Calcium carbonate</u>

In this study soils containing any free calcium carbonate were grouped with the calcareous soils. The calcium carbonate analyses were used as a help in classification and to assess the actual levels of carbonates present. If large amounts of free carbonate are present the exchangeable calcium results will contain a large contribution from water soluble calcium.

The method used for the determinations (p. 483) is a simple one, but the resultsare sufficiently accurate for the above uses. The quantities present were very small and an indication of the strong leaching found under the climatic conditions of the area. The rendzinas contained between 1 and 3% and the brown calcareous soils 0.5-1.0 close to the surface and 1.0-1.5% nearer the soil - limestone bedrock interface.

C. 11. Extractable iron

The readily extractable iron is thought to be the active fraction available for mobilisation during podzolisation. In brown earths the extractable iron values generally remain constant down the profile whereas in a podzol a minimum will be found in the A_2 horizon followed by a maximum in the B and a subsequent decrease in the C horizon. There are difficulties of interpretation as the readily extractable iron in the B horizon may have been eluviated from the A_2 horizon or it may have been released within the B horizon by in situ weathering. Comparison of values of extractable iron from soils on different parent materials is suspect as they will reflect, to some extent, the total iron contents of the parent materials. An increase in extractable iron paralleling an increase in clay content may be due to translocation of an iron rich clay rather than podzolisation.

The method used, i.e. that devised by Deb (1950), was until recently one of the most popular. As the amount of iron extracted depends upon the extractant the values obtained are of a purely conventional significance. The use of a commonly employed method is, therefore, to be recommended. Recently, various authors have suggested alternative extractants as it is now though that that of Deb removes some of the more stable iron compounds.

Extractable iron analyses were only carried out on soils which had been tentatively assigned to the acid brown earths or brown podzolic soils. It was hoped that the results would confirm the classification of these soils. Variations in the values obtained were present down the profile of the acid brown earths but these were usually fairly small; a maximum was generally found in the B horizon. In the brown podzolic soils a very marked maximum in the values was found in the B horizon and a minimum in the A : the increase in the two profiles quoted was 1.3 (A horizon) to 4.5 (B horizon) in profile 22 B.P.S. and 0.9 to 2.6% in 21 B.P.S. The values for the B horizons are also greater in the brown podzolic soils than in the acid brown earths. It is worth noting that an increase in clay content down the profile is found in acid brown earths but not in the brown podzolic soils. On the basis of these analyses it would seem that the soils were justifiably separated and that there are indications of iron movement in the podzolic soils.

C. 12. Heavy mineral analyses

As rocks and parent materials often have a characteristic suite of heavy minerals a great deal can be gained from their study. These studies are carried out on the fine sand or silt fractions and as these are relatively immobile fractions of the soil they are particularly suited to parent material studies. Simple techniques can be used to separate and concentrate these minerals and the most frequently used employs heavy liquids with bromoform the one most commonly used. The minerals of lower specific gravities than the heavy liquid remain in suspension in it while the denser minerals settle out. Once separated the heavy minerals are cleaned, mounted and then identified and counted using a petrological microscope.

This type of analysis was used in an attempt to differentiate sedentary soils, formed from the insoluble residue of the limestone, from those formed in a transported material (Chapter 13). The insoluble residue of the limestone contains very few heavy minerals and those present were generally zircon or fluorite.

Most of the soils contained many more grains and a more diverse suite, although still not a very rich one. The commonest minerals being garnet, tourmaline, rutile, zircon and fluorite plus a large number of opaque minerals which were not identified. These soils were clearly not derived from the insoluble residue of the limestone. Some rendzinas do contain a limited suite dominated by fluorite and zircon and may be dominated by the insoluble residue of the limestone. The method was used in a qualitative manner (p. 489) but despite this the results obtained are a useful and reliable indicator when used with other evidence.

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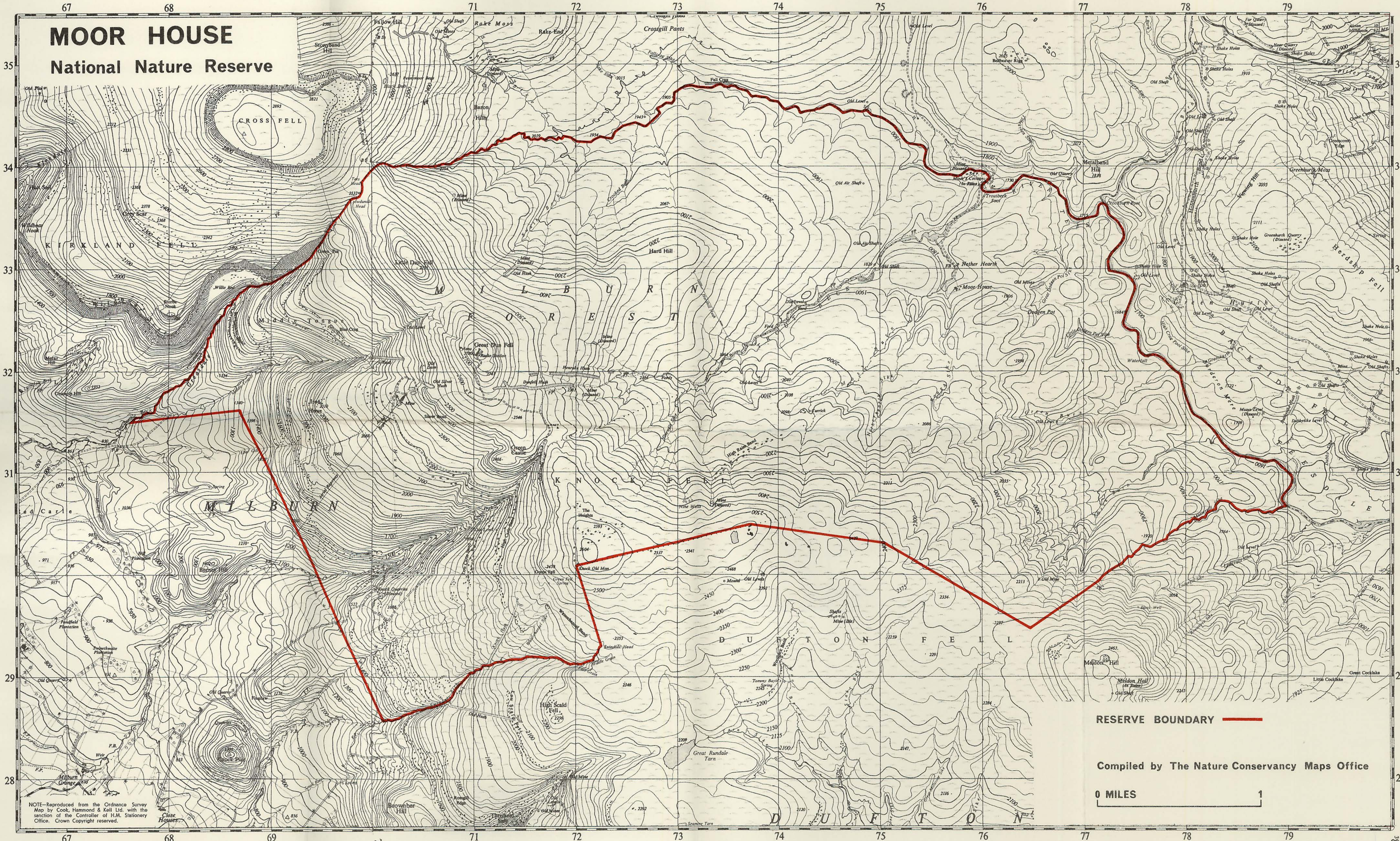
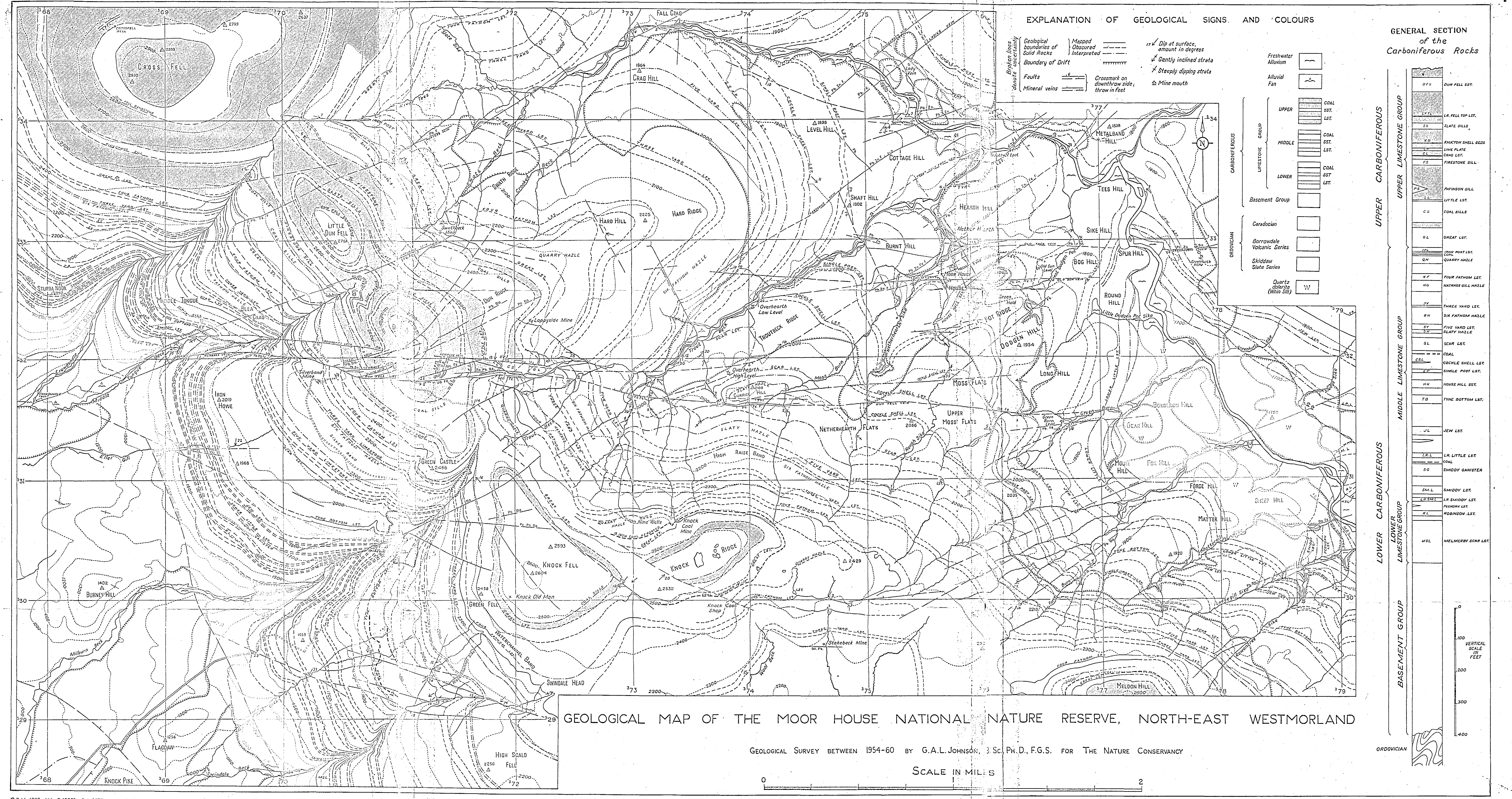

MOOR HOUSE
National Nature Reserve
CROSS FELL
KIRKLAND FELL
M I L B U R N F O R E S T
Great Dun Fell
Little Dun Fell
Hard Hill
Knock Fell
M I L B U R N
D U F T O N F E L L
D U F T O N
Great Rundale Tarn
High Scald Fell
Meldon Hill
Bellbeaver Rigg
Moss House
Nether Hearth
Crossgill Pants
Backside Fell
Herdship Fell
Greenhurth Moss
Meldon Hill
RESERVE BOUNDARY
Compiled by The Nature Conservancy Maps Office
0 MILES 1
NOTE—Reproduced from the Ordnance Survey Map by Cook, Hammond & Kell Ltd. with the sanction of the Controller of H.M. Stationery Office. Crown Copyright reserved.

FIG. 7



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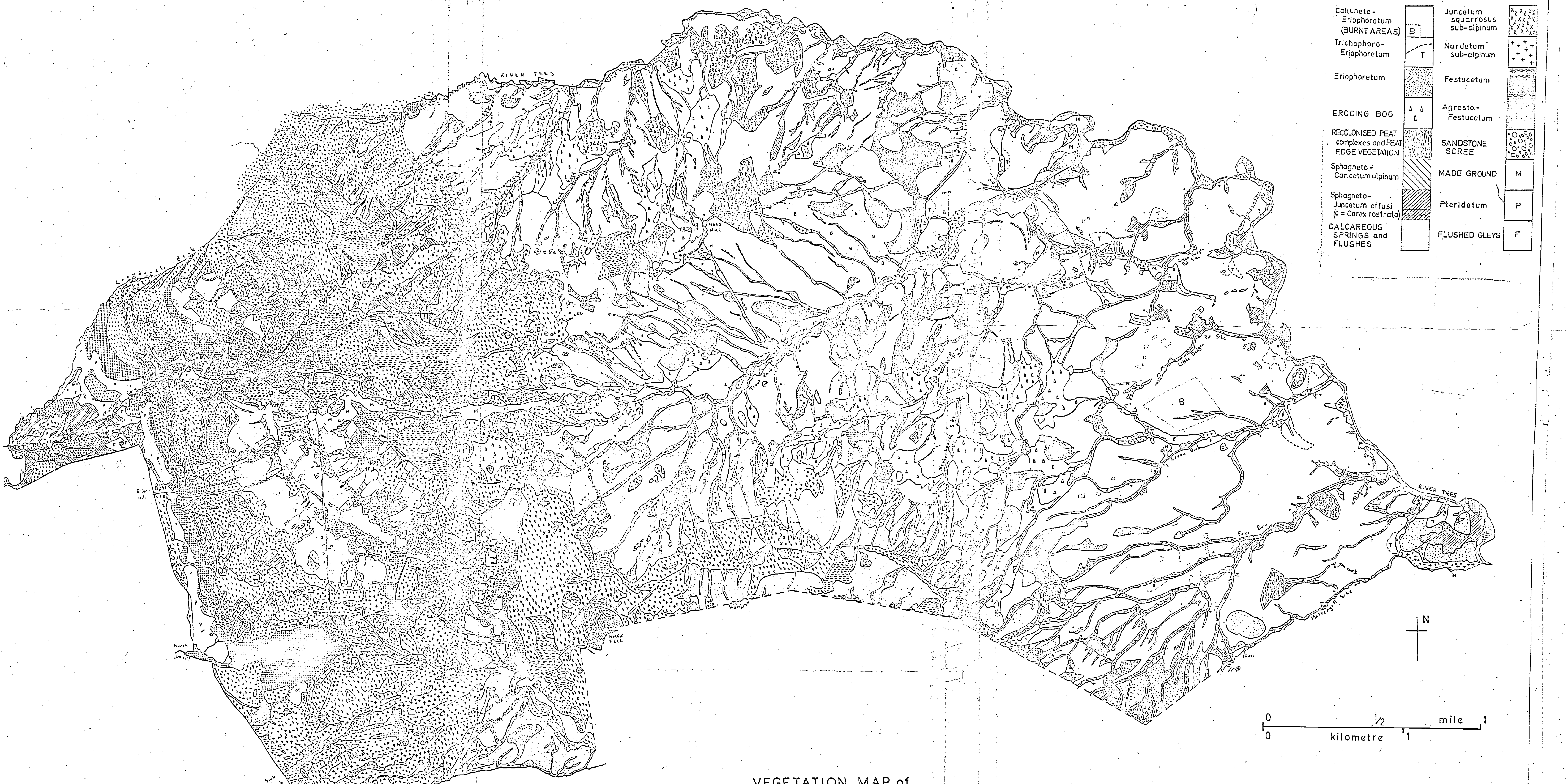

VEGETATION MAP of
MOOR HOUSE N. N. R.
area surveyed by A.Eddy, 1960-1962, map c[illegible]ied with
alterations by D.Welch, 1965.

SECTION ALONG ROUGH SIKE TRENCH

FIG. 35